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*Final*

# **Sitewide Groundwater Performance Monitoring Plan**

## **Bayer CropScience Institute Facility, Institute, West Virginia**

Prepared for

**Union Carbide Corporation**  
A Wholly Owned Subsidiary of The Dow Chemical Company

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**CH2MHILL®**



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# Acronyms and Abbreviations

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µg/L	micrograms per liter
bgs	below ground surface
CAH	chlorinated aliphatic hydrocarbon
CCR	<i>Current Condition Report</i>
CMP	Corrective Measures Proposal
COC	constituent of concern
CSM	conceptual site model
ENB	ethylidene norbornene
ESL	ecological screening level
facility	Bayer CropScience facility in Institute, West Virginia
GMP	<i>Groundwater Monitoring Plan</i>
LEL	lower explosive limit
PCE	tetrachloroethene
PHC	petroleum hydrocarbon
PMP	performance monitoring plan
RCRA	Resource Conservation and Recovery Act
RSL	regional screening level
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TAL	target analyte list
UCC	Union Carbide Corporation
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
WVDEP	West Virginia Department of Environmental Protection



# Introduction

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This *Sitewide Groundwater Performance Monitoring Plan* (PMP) has been prepared for the Union Carbide Corporation (UCC) on behalf of Bayer CropScience LP at the Bayer CropScience facility in Institute, West Virginia (hereafter referred to as the “facility”). UCC is a wholly owned subsidiary of The Dow Chemical Company. This PMP was prepared in accordance with the streamlined Corrective Measures Proposal (CMP) process toward Resource Conservation and Recovery Act (RCRA) Corrective Action Complete. The U.S. Environmental Protection Agency (USEPA) approved use of the streamlined CMP process in August 2007. The PMP also was prepared in accordance with the sitewide groundwater approach summarized in the *Bayer CropScience Institute Facility Sitewide Groundwater Strategy* presentation to the West Virginia Department of Environmental Protection (WVDEP) and USEPA on April 21, 2010, and September 20, 2010 (CH2M HILL 2010a, 2010b). WVDEP and USEPA provided electronic written approval to UCC on April 27 and 29, 2010, respectively, of the approach for managing sitewide groundwater. This PMP will update and supercede the *2009 Groundwater Monitoring Plan* (GMP; CH2M HILL 2009a) for the facility.

## 1.1 Site Description and Background

The facility is an industrial park located between the Kanawha River and West Virginia State Route 25 in Institute, West Virginia. The facility consists of two distinct areas, the main chemical plant and the wastewater treatment unit, which are separated by a 0.5-mile stretch of land that is not part of the facility and is not owned by Bayer CropScience. The main chemical plant, the focus of this PMP, occupies approximately 350 acres of land. The location of the facility is shown on Figure 1.

Site investigation activities were initiated in 1992 following issuance of the RCRA corrective action permit (CH2M HILL 2009b). Since then, several investigation and remedial activities have occurred and are ongoing. Historical and current (as of February 2011) interim remedial measure areas at the facility are shown on Figure 2.

Quarterly groundwater monitoring of groundwater constituents of concern (COCs) across the site began in March 2009 to better understand potential exposure pathways, monitor progress toward meeting cleanup criteria, and obtain a chemical and temporal baseline of the monitoring well network (CH2M HILL 2010c). Potential groundwater exposure pathways are defined in the *Current Condition Report* (CCR; CH2M HILL 2009b) and include soil leaching to groundwater, groundwater use for human consumption, volatilization to indoor air, and groundwater to surface water discharge. In accordance with the GMP for the facility (CH2M HILL 2009a), 40 monitoring wells across the site were identified to be sampled quarterly and include wells that serve as compliance points along the property boundaries and river (perimeter monitoring wells), wells that monitor constituent plumes, and wells that serve as sentinel wells downgradient of the constituent plumes.

## 1.2 Preliminary Remedial Action Objectives

The following preliminary remedial action objectives have been identified for the facility:

- Demonstrate no further action needed, where appropriate
- Prevent direct contact exposure pathways
  - Maintain waste materials and impacted soil in place
  - Prevent unacceptable exposure (direct contact or inhalation)
    - Appropriate barriers
    - Institutional/engineering controls
- Vapor intrusion
  - Use institutional and/or engineering controls to prevent unacceptable exposures
- Minimize leaching to groundwater
  - Reduce mass in soil and/or reduce infiltration rates
- Groundwater
  - Prevent human exposure to groundwater
  - Prevent groundwater discharge to surface water at concentrations exceeding surface water criteria
  - Use focused remedies (“hot spot” treatment coupled with monitoring progress toward meeting cleanup criteria)

This PMP focuses on those remedies related to exposure to groundwater.

## 1.3 Proposed Groundwater Approach

The sitewide strategy for groundwater is a several-pronged approach with the overarching goal of preventing unacceptable human and ecological exposure to groundwater. This approach includes institutional controls, focused remedies, and groundwater monitoring and previously was summarized in presentations to WVDEP and USEPA (CH2M HILL 2010a, 2010b). In April 2010, WVDEP and USEPA approved the approach for managing sitewide groundwater.

### 1.3.1 Institutional Controls

Institutional controls will be used to prevent potential human exposure to groundwater at the facility through a groundwater use restriction contained in an Environmental Covenant. If a potential human exposure to groundwater is identified at offsite locations, an Environmental Covenant may be put in place for those areas. The Environmental Covenant may:

- Prohibit the installation of new production wells and use of groundwater to prevent a human exposure pathway and the migration of constituents in groundwater

- Require the use of engineering controls (where necessary) for new buildings planned at the facility to mitigate the potential for a groundwater to vapor intrusion pathway

### **1.3.2 Focused Remedies**

Focused corrective action remedies may be implemented to reduce constituent concentrations in soil, prevent offsite migration of impacted groundwater above site-specific criteria to adjacent offsite properties or the Kanawha River, and accelerate the reduction in constituent mass in “hot spot” areas. Focused groundwater corrective actions and vapor mitigation will be considered for buildings where unacceptable risk is present because of vapor intrusion.

### **1.3.3 Groundwater Monitoring**

A sitewide groundwater monitoring program will be implemented that will achieve the following objectives:

- Demonstrate that constituent concentrations at the site are stable or decreasing
- Identify areas of the site where active remediation may be necessary
- Monitor the perimeter of the site for future migration of COCs above applicable criteria

The following sections describe the basis of the groundwater monitoring and performance monitoring components of the groundwater remedy.

## **1.4 Objective**

The main objective of the PMP is to establish a plan that consists of systematic monitoring and evaluation of groundwater conditions at the facility to detect and respond to changes in site conditions. Performance monitoring objectives will include onsite containment, plume stability, and reduction in constituent mass.



## SECTION 2

# Groundwater Monitoring

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A step-wise approach (Sections 2.1 through 2.4) was used to establish the groundwater monitoring network outlined in Section 2.5. To develop the groundwater monitoring program, performance standards, and metrics, it is important to understand the conceptual site model (CSM). The CSM has been updated based on groundwater data collected as part of ongoing groundwater monitoring and is presented in Section 2.1. The COCs for the site are presented in Section 2.2. Key constituents, a subset of the COCs, were further grouped (Section 2.3) to aid in developing an approach for estimating the mass of constituents in subsurface at the site (Section 2.4).

## 2.1 Revised Conceptual Site Model

The CSM for the facility was revised based on new information available following publication of the CCR (CH2M HILL 2009b) and re-evaluation of existing data. The updated CSM for groundwater is described in the following paragraphs.

Alluvial deposits approximately 55 to 60 feet thick associated with the Kanawha River underlie the site (CH2M HILL 2010c). The alluvial deposits are thickest near the river and thin inland. These deposits consist of interbedded gravel, sand, silt, and clay deposits as shown on the geologic cross section (Figure 3). Generally speaking, the alluvial deposits represent a “fining upwards” sequence with coarser material (sand and gravel) more prevalent at the base of the unit and fine-grained material (silt and clay) more prevalent at the top. The relative amount of sand and clay varies across the site. As shown on Figure 4, a thick layer (greater than 30 feet thick) of silt/clay occurs adjacent to the Kanawha River and along the north-northeast boundary of the facility. The thick silt/clay layer occurs where the upper portion of the aquifer normally would be and is underlain by a thin layer of aquifer sands. The silt/clay thickness generally is thinner (less than 30 feet thick and absent in some areas) within the central portion of the facility.

Permeable, water-saturated material is present at most locations within the main facility, with the possible exception of a small area near the northeastern corner of the site where there is limited information (Figure 5). An isopach map of permeable aquifer thickness is presented on Figure 5. Because of stratification of COC concentrations beneath the facility, the aquifer has been subdivided into two zones: shallow and deep (CH2M HILL 2009b). The shallow aquifer zone extends from the upper depth of the permeable aquifer (15 to 20 feet below ground surface [bgs]) to approximately 30 feet bgs, and the deep aquifer zone extends from 30 feet bgs to the bedrock surface, generally located from 55 to 60 feet bgs. The shallow aquifer zone does not occur continuously across the facility site and is absent in areas where the silt/clay thickness is 30 feet thick or more. Monitoring wells screened within the silt and clay deposits (0 to 30 feet bgs) are no longer considered shallow aquifer monitoring wells as previously classified in the CCR (CH2M HILL 2009b) and comprise MW-101, TW-15, TW-22, TW-23, TW-48, VW-4A, TW-27R, and TW-63A. In some areas of

the site, locally perched groundwater is encountered at depths ranging from 7 to 13 feet bgs within the silt/clay unit. Groundwater in these horizons is laterally discontinuous.

Groundwater in the aquifer at the facility typically occurs from 15 to 20 feet bgs. The aquifer is unconfined where the silt/clay layer is less than 15 to 20 feet thick, though locally it may be semiconfined if low-permeability clays are present, such as near the Kanawha River. The aquifer at the facility is recharged primarily by infiltration from precipitation. Although no bedrock wells have been installed at the facility, minimal groundwater likely enters the alluvial aquifer from bedrock that is recharged in the adjacent upland areas (CH2M HILL 2009b). Groundwater within the shallow and deep zones of the alluvial aquifer generally flows toward the Kanawha River.

## 2.2 Groundwater Constituents of Concern

Groundwater COCs were identified in the CCR (CH2M HILL 2009b) and include volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals (Table 1). Metals are not included as part of the groundwater monitoring program because they are not considered a primary driver for risk because of the limited opportunities for exposure (CH2M HILL 2009b). Human exposure to metals in groundwater is limited to exposure through ingestion. Current and future institutional controls will restrict potential human exposure to metals in groundwater by prohibiting the use of groundwater at the site.

The groundwater COCs listed in the CCR (CH2M HILL 2009b) were compared to the list of target analytes included in the 2009 GMP (CH2M HILL 2009a). Based on this comparison, the target analyte lists (TALs) for VOCs and SVOCs were revised (Table 1). Several compounds were added or removed from the CCR COC list for the following reasons:

- Total xylenes often are found in combination with benzene, toluene, and ethylbenzene in groundwater at the facility and were added to the COC list.
- Carbon disulfide and styrene were added to the COC list because they have been detected in soil and groundwater above screening levels during recent investigation activities (October 2010).
- Phenol was detected at monitoring wells adjacent to the Kanawha River above the ecological screening level (ESL) of 4 micrograms per liter ( $\mu\text{g/L}$ ; USEPA 2006) and was added to the COC list.
- Isopropyl ether was detected in one historical product sample at concentrations above the screening level defined in the CCR ( $83 \mu\text{g/L}$ ; CH2M HILL 2009b); however, the screening value has changed ( $830 \mu\text{g/L}$ ; USEPA 2010), and the concentration is below the current screening level. Therefore, this compound was removed from the COC list.

## 2.3 Key Constituents of Concern

Based on known site conditions, key groundwater COC groups were identified based on common spatial occurrence, an association between the COCs resulting from constituent decay (i.e., breakdown products), or an overall occurrence of concentrations in groundwater above screening levels. These groupings were created to facilitate streamlined monitoring of plume dynamics, specifically the change in the dissolved constituent mass of the COC



groups over time. Collectively, the COC groups represent the majority of the COC mass in groundwater. Key COC groupings are identified in Table 1 and briefly described in the following sections.

### **2.3.1 Group 1: Chlorinated Aliphatic Hydrocarbons**

The first key COC grouping consists of chlorinated aliphatic hydrocarbons (CAHs). Individual compounds that comprise this group are:

- Tetrachloroethene (PCE)
- Trichloroethene
- 1,1-Dichloroethene
- cis-1,2-Dichloroethene
- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,1,2-Trichloroethane
- Vinyl chloride

These compounds generally occur together or are associated by biotransformation processes (parent-daughter reactions). At the facility, the primary risk driver of the CAH group is PCE because of the concentrations found in groundwater above screening levels.

### **2.3.2 Group 2: Petroleum Hydrocarbons**

The second key COC grouping consists of petroleum hydrocarbons (PHCs). Individual compounds that comprise this group are:

- Benzene
- Toluene
- Ethylbenzene
- Total xylenes
- Naphthalene

These compounds generally occur together in groundwater at the facility and biodegrade under similar conditions. The main risk driver of the PHC group is benzene because of the concentrations above screening levels found in groundwater at the facility.

### **2.3.3 Group 3: Carbon Tetrachloride**

The third COC group consists of only one compound, carbon tetrachloride. Carbon tetrachloride occurs in groundwater at concentrations above screening levels over a large portion of the facility and therefore is a risk driver for the site. The spatial distribution of carbon tetrachloride is significantly different from the other CAH compounds.

### **2.3.4 Group 4: Chloroform**

The fourth COC group consists of only one compound, chloroform. Similar to carbon tetrachloride, chloroform occurs in groundwater at concentrations above screening levels over a large portion of the facility and therefore is a risk driver for the site. Chloroform often is associated with carbon tetrachloride, but the spatial distribution of chloroform is significantly different from carbon tetrachloride and other CAH compounds; thus, chloroform will be evaluated separately.

## 2.4 Thiessen Polygon Method for Estimating Constituent Mass

To assess and document achievement of remedial action objectives, an approach to monitoring and estimating sitewide total dissolved mass of constituents in the aquifer was developed. To track constituent mass, key COC groups were defined that make up the majority of the constituent mass in the aquifer. These groupings are described in Section 2.3. A consistent approach to calculating the total mass of constituents in the aquifer and how this mass changes over time was desired. The method selected is the Thiessen polygon method (USEPA 1998).

The Thiessen method assumes that each monitoring location can be represented by a polygon of defined area, thickness, and concentration. The method was developed in the field of hydrology for use in estimating areas associated with point rainfall measurements within rain gauge networks (USEPA 1998). The Thiessen method defines a polygon by assuming the concentration measured at a given location is equal out to a distance midway to the monitoring locations located next to it in all directions. The boundary of the Thiessen polygon network was estimated assuming a 10 percent buffer past the outermost wells. The area of each polygon then was used to estimate the mass associated with a given monitoring well by assigning a thickness to the polygon that corresponds to the aquifer thickness at that particular location.

Although steady-state conditions can be tentatively identified by observing the time course of constituent concentrations at specific monitoring locations, a more desirable approach is to investigate constituent mass distribution throughout the entire plume. The Thiessen polygon method is a spatially integrated approach that uses sitewide mass estimates of key COCs to evaluate changes in plume mass over time. This approach provides a better understanding of plume dynamics, including detection of an increase or decrease in total plume mass that is less sensitive to small transient changes. Overall, the Thiessen polygon method allows for the systematic monitoring and evaluation of groundwater concentration data to detect and respond to changes in COC mass. In simple terms, the constituent mass is calculated by multiplying the concentration measured in a well by the volume (polygon area multiplied by the impacted vertical saturated thickness) for a set of predefined polygons and then summing the polygons to arrive at a total mass for a given COC group for the site. Because the polygons are defined at the start of the monitoring program and do not change, the total mass can be determined easily as new concentration measurements are obtained. These data can then be used to evaluate changes in mass over time.

Implementing the Thiessen polygon method consists of the following steps:

1. Identify the monitoring well network that will be used to track plume mass
2. Construct Thiessen polygons around individual monitoring wells and establish the Thiessen well network
3. Calculate the area of individual Thiessen polygons based on the monitoring well network
4. Estimate total dissolved-phase constituent mass in individual polygons for each key COC grouping

5. Estimate the plume mass for each key COC grouping by summing the mass across all polygons
6. Compare change in estimated total dissolved-phase plume mass over time

### **2.4.1 Development of Thiessen Polygon Monitoring Well Network**

The first step in implementing the Thiessen polygon method is to establish the “optimum” coverage of a Thiessen polygon monitoring well network. The optimum network was created using an iterative approach to maximize coverage of the monitoring well network while minimizing monitoring locations. In addition to removing redundant monitoring locations, areas sparsely monitored and exhibiting high concentrations of key COCs also were identified. The initial Thiessen polygon monitoring network was calibrated to prevent a single monitoring well location contributing an abnormally high percentage of the total plume mass. As previously discussed, areas containing sparsely distributed monitoring points will have much larger polygons. These large polygons can overweight concentrations to the point where a single monitoring location accounts for most, if not all, of the estimated plume mass and is unduly influencing decisions concerning plume stability. In these instances, installation of additional monitoring points can help refine the mass estimate.

Several iterations of the Thiessen polygon monitoring well network were performed for the facility, starting with a baseline monitoring well network. The first baseline iteration started with 53 wells, which included the 40 wells from the 2009 GMP monitoring well network (CH2M HILL 2009a) and 13 additional wells located across the site that had been sampled historically (Table A-1, Appendix A). During the iterative process, the monitoring well network was progressively revised from the previous network following an evaluation of the key COC mass over time. The baseline and the final, optimized version of the Thiessen monitoring well networks are presented in more detail in Appendix A, including a comparison of the mass trends for each network (Figures A-1 through A-4).

As shown on Figures A-1 and A-2, a small portion of the northern-most COC plumes fall outside of the Thiessen polygon network. These small areas of the plumes are based on groundwater samples collected using direct push techniques. Because these techniques only interrogate a small portion of the aquifer, COC concentrations probably are biased high as compared with groundwater samples collected from nearby monitoring wells. The amount of mass associated with these areas is assumed small compared with the main regions of the plume and generally is offset by weighting each monitoring well by the entire polygonal area. For instance, COC concentrations for TW-56 are assumed constant within its polygon. This polygon includes uncontaminated groundwater north of TW-56. The Thiessen polygon method monitors the change in mass over time and is not concerned with calculating an absolute estimate of mass. Table A-2 in Appendix A presents a summary of the saturated aquifer thickness associated with each well in the Thiessen polygon network and how that value was determined.

### **2.4.2 Data Gap Analysis**

During the iterative Thiessen polygon method process, two areas were identified where additional aquifer information may be beneficial. The first area is near Solid Waste Management Unit (SWMU) 18/22 (1700 Robb Station/Ethylidene Norbornene [ENB] Unit

and 1600 Robb Station/ENB Unit) where several COCs, in particular benzene, were identified in the deep aquifer zone during the 2006 RCRA facility investigation at boring location MIP-18-2 (CCR Appendix B, CH2M HILL 2009b). A permanent monitoring well is not located in this area of the site; therefore, a monitoring well (Proposed Well 1) is proposed near former boring location MIP-18-2 (Figure 6).

The second area is near monitoring well TW-57, which historically has had the highest concentrations of chloroform at the site. Installation of a new monitoring well (Proposed Well 2) is recommended east of TW-57 to prevent over-weighting of constituent mass at the Thiessen polygon associated with TW-57 (Figure 6). Proposed Well 2 will be screened in the deep aquifer zone and will further define the extent of the chloroform plume east of TW-57.

## 2.5 Groundwater Monitoring Network and Frequency

The following categories of monitoring wells were established to meet the objectives defined in Section 1.3.3:

- Thiessen wells: Monitor changes in dissolved constituent mass at the site over time using the Thiessen polygon method. Thirty-six wells have been identified to comprise the Thiessen monitoring well network.
- Sentinel wells: Monitor changes in constituent distribution and plume stability using a series of sentinel wells. Eight sentinel monitoring wells have been identified for this purpose.
- Perimeter wells: Monitor concentrations to determine whether dissolved constituents are migrating offsite at concentrations exceeding applicable criteria. Fifteen perimeter monitoring wells have been identified for this purpose.

The sentinel and perimeter monitoring wells are part of the Thiessen monitoring well network. The monitoring wells and their intended purpose are listed in Table 2 and shown on Figure 6.

In addition to the 36 Thiessen monitoring wells, TW-27R will be monitored (if conditions are safe in the area) to evaluate acetone in groundwater near SWMU 15. Monitoring well TW-27R is near SWMU 15 in an area where high concentrations of acetone have been measured historically. Acetone in groundwater generally has been limited to a small area of the site near SWMU 15. In 2008, high lower explosive limit (LEL) readings were measured at TW-27R and at a nearby borehole in excess of safe working conditions. A vapor sample collected from the borehole had a concentration of 23.6 percent methane. No landfill activities have been documented in the area, and the methane is not believed to be naturally occurring. Methyl mercaptan also was detected in the air sample, indicating an anthropogenic source. The LEL readings have not diminished over time; therefore, work cannot be conducted in this area until the source of the high LEL readings is mitigated.

The 37 identified monitoring wells (Table 2) will be sampled annually for the TAL compounds listed in Table 3. This monitoring frequency was determined following a review of groundwater elevation data across several seasons (Figures 4-1 through 4-7 of the 2009 *Groundwater Monitoring Report* [CH2M HILL 2010c], included in Appendix B) and an evaluation of temporal concentrations of key COCs (Figures B-1 through B-8, Appendix B).

Figures B-1 through B-8 illustrate there is no apparent seasonal affect on COC concentrations. Annual groundwater monitoring, therefore, is appropriate for tracking COC concentrations over time to detect changes in constituent mass or document plume stability. Annual groundwater data would support removal of potential statistically insignificant seasonal change (i.e., background noise) from the dataset.

### **2.5.1 Groundwater Elevation Measurements**

Water levels will be measured during each event to confirm groundwater flow patterns at the site. Water level measurements will be collected from the wells listed in Table 2. These measurements will provide sufficient data to determine the potentiometric surface in the aquifer at the facility. These measurements will be collected using a handheld water level meter within a 12-hour period to the extent possible during each annual groundwater sampling event. Water levels will be collected before groundwater sample collection. Water level measurements will be collected from the wells in accordance with the standard operating procedure for groundwater level measurements (Appendix C).

### **2.5.2 Groundwater Sample Collection**

In accordance with this PMP, groundwater samples will be collected at 37 monitoring wells annually in the same quarter each year. Groundwater samples will be collected for the site-specific VOCs listed in Table 3 using USEPA Method 8260B at all monitoring wells. Six groundwater samples will be collected for the site-specific SVOCs listed in Table 3 using USEPA Method 8270C – ultra low level. The analytical methods and other laboratory related information are summarized in Table 4. Groundwater samples will be collected using low-flow groundwater sampling techniques in accordance with the standard operating procedure for low-flow groundwater sampling (Appendix C).



## Performance Monitoring Standards

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Three groundwater performance monitoring standards have been identified: onsite containment of constituents, stability of constituent plumes, and reduction in constituent mass over time. These standards will be met by systematic monitoring and evaluation to detect and respond to changes in site conditions. The performance monitoring standards are described in the following sections.

### 3.1 Onsite Containment

The first objective is to ensure that groundwater containing constituents at concentrations that exceed applicable risk-based criteria does not migrate offsite. The performance standards for this objective are based on groundwater migration to offsite properties where human receptors are the risk driver and groundwater migration to the Kanawha River where ecological receptors are the risk driver. The specific standards are as follows:

- The USEPA regional screening levels (RSLs; USEPA 2010) will be applied to groundwater data collected at monitoring wells adjacent to offsite property boundaries (i.e., perimeter wells along the eastern and western facility boundaries and perimeter wells along the river [Table 5]). For perimeter wells along the river, if an RSL is exceeded, a dilution factor will be calculated to account for dilution of pore water concentrations as it enters the water column and applied to the screening levels. The dilution factor will be calculated using a ratio of groundwater vs. Kanawha River discharge rates, and Table 1 will be updated with the revised screening level.
- The USEPA ESLs (USEPA 2006) will be applied to groundwater data collected at monitoring wells adjacent to the Kanawha River (Table 5). If an ESL is exceeded, site-specific criteria may be developed considering Kanawha River pore water concentrations, and Table 5 will be updated with the revised screening level.

The performance metric for onsite containment of groundwater will be to compare the concentration of groundwater COCs in the perimeter wells to risk-based criteria listed in Table 1 (if site-specific criteria are developed, they will be added to Table 1 in a future update to this plan). The performance metric is met if COC concentrations are below risk-based criteria in the wells.

### 3.2 Plume Stability

The second objective is to ensure the groundwater constituent plumes onsite are stable or decreasing in size and are not migrating into areas of the facility where they could result in potential unacceptable risk to human receptors. The performance standard will be to ensure constituent concentrations in groundwater monitoring wells across the facility are collectively stable or decreasing in concentration. This performance standard also will help identify if a potential vadose zone source area is present at the site that was not identified previously (e.g., a significant increase in COC concentrations occurs).

Groundwater key COC concentration trends will be monitored in groundwater monitoring wells. In addition, several other groundwater COCs (other targeted COCs) will be evaluated because of their potential for unacceptable risk to human health or the environment coupled with their isolated or irregular occurrence onsite. The other targeted COCs include acetone; 1,4-dioxane; dichlorodifluoromethane; trichlorofluoromethane; bis(2-chloroethyl)ether; bis(2-chloroisopropyl)ether; bis(2-ethylhexyl)phthalate; phenol; and isophorone. Trends in other targeted COC concentrations that will be evaluated on a well-by-well basis are summarized in Table 6. The performance metrics for stable or decreasing groundwater COC plumes are:

- If more than 90 percent of the wells exhibit stable or decreasing concentrations of COC trends, then the standard is achieved.
- If all sentinel wells exhibit stable or decreasing concentration trends, then the standard is achieved.

To evaluate if key groundwater COCs and other targeted COC plumes are stable or decreasing, monotonic trend analysis using the Mann-Kendall test (Gilbert 1987) will be conducted to make statistical inferences concerning COC concentration trends. Trend testing can determine if there is a statistically significant trend over the period of monitoring and can determine the magnitude (i.e., slope) of the trend. In identifying a decreasing trend, it may be possible to demonstrate that the level of contamination has decreased relative to historical behavior and indicate how rapidly levels are decreasing.

The Mann-Kendall test is a nonparametric statistical test for zero slope of the first-order regression of time-ordered concentration data versus time at an *a priori* specified significance level. The Mann-Kendall test is based on the idea that a lack of trend should correspond to a time series plot fluctuating randomly about a constant mean level, with no visually apparent upward or downward pattern (USEPA 2009). The method proceeds by calculating the slope of the change in a measurement per change in time, and determining the mean slope for a series of measurements. When seasonal effects influence data, a trend estimator adjustable for seasonal variation (e.g., seasonal Mann-Kendall test and seasonal Mann-Kendall slope estimator) is recommended. However, based on historical groundwater concentration data collected from the site, adjustment for seasonality is not required.

As a non-parametric procedure, the Mann-Kendall test does not require the underlying data to follow a specific distribution. Ranks of the data are not explicitly used in forming the test statistic as with the Wilcoxon rank-sum. Only the relative magnitudes of the concentration values are needed to compute the Mann-Kendall statistic, not the actual concentrations. Nondetects will be treated by assigning them a value of half the method detection limit. Any pair of tied values or any pair of nondetects is simply given a score of zero in the calculation of the statistic.

A significance level of 0.1 to 0.05 (i.e., 90 to 95 percent confidence) will be used in the Mann-Kendall tests:

- A strong trend (either increasing or decreasing) will be indicated by a confidence level greater than or equal to 95 percent.



- A weak trend (either increasing or decreasing) will be indicated by a confidence level less than 95 percent but greater than or equal to 90 percent.
- A relatively stable trend will be indicated by a confidence level less than 90 percent and coefficient of variation less than 1.

If the non-parametric analysis is indeterminate in terms of detecting a trend at the stated confidence level, professional judgment will be used to assess the data based on the trend plots and recommendations will be provided to USEPA to discuss the appropriate path forward.

### 3.3 Reduction in Constituent Mass

The third objective is to ensure groundwater quality continues to improve over time as measured by a reduction in the COC mass dissolved in groundwater. This performance standard will ensure water quality continuously improves.

A non-parametric trend analysis, similar to the Mann-Kendall test described in Section 3.2, of groundwater COC mass will be performed for each key COC grouping (CAHs, PHCs, carbon tetrachloride, and chloroform) using the Thiessen polygon method. The performance standard is achieved if a reduction in groundwater COC mass is measured for each key COC grouping at the facility, or if the COC mass reaches asymptotic conditions after reducing over time.

### 3.4 Contingency Plan

If the performance metrics for any of the performance standards are not met, a phased contingency plan will be triggered that consists of the following steps:

1. Site data will be evaluated to determine the cause for the observed excursion from the metric (COC mass increase, unstable plume, increase concentration in sentinel or perimeter wells) and whether the condition could result in a potential unacceptable exposure pathway risk.
2. Additional data will be collected, if appropriate, to assess site conditions and evaluate the need for mitigation.
3. The evaluation of the total COC mass in groundwater will be reported in the annual monitoring report (refer to Section 4), and recommendations will be made for further actions, if any.
4. If necessary, a focused remedy will be implemented to manage unacceptable risk and achieve the remedial action objectives for the facility.

If unacceptable risks to human health or the environment are determined to exist at any time during the evaluation process, UCC will contact USEPA to discuss the appropriate path forward to address the risk.



#### SECTION 4

## Compliance Reporting

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A groundwater performance monitoring report will be prepared and submitted to USEPA annually within 6 months following each groundwater sampling event. This report will include the following:

- Tabulated analytical data compared to applicable RSLs and ESLs
- Tabulated groundwater elevation data
- Potentiometric surface map
- Summary of focused remedies implemented at the facility
- Discussion of the evaluation of the performance monitoring standards, including graphics to convey trends (e.g., trend graphs, mass plots)
- Recommendations on a path forward if the performance monitoring metrics are not met



## References

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CH2M HILL. 2009a. *2009 Groundwater Monitoring Plan*. Bayer CropScience Institute Facility. Prepared for USEPA. March.

CH2M HILL. 2009b. *Current Conditions Report*. Bayer CropScience Institute Facility. Prepared for Union Carbide Corporation. October.

CH2M HILL. 2010a. *Bayer CropScience Institute Facility Site-Wide Groundwater Strategy* (Powerpoint Presentation). Bayer CropScience Institute Facility. Prepared for WVDEP and USEPA. April 21.

CH2M HILL. 2010b. *Bayer CropScience Institute Facility Site-Wide Groundwater Proposed Performance Metrics* (Powerpoint Presentation). Bayer CropScience Institute Facility. Prepared for WVDEP and USEPA. September 20.

CH2M HILL. 2010c. *2009 Groundwater Monitoring Report*. Institute Facility, Institute, West Virginia. Prepared for Union Carbide Corporation. June.

Gilbert, R. O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Wiley, New York.

U.S. Environmental Protection Agency (USEPA). 1998. *Monitoring and Assessment of In Situ Biocontainment of Petroleum Contaminated Ground-Water Plumes*. EPA/600/R-98/020. Office of Research and Development, Washington DC. February.

U.S. Environmental Protection Agency (USEPA). 2006. *Freshwater Screening Benchmarks, Region III Biological Technical Assistance Group (BTAG)*. July.

U.S. Environmental Protection Agency (USEPA). 2009. *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance*. EPA-530-R-09-007. Office of Resource Conservation and Recovery, U.S. Environmental Protection Agency. March.

U.S. Environmental Protection Agency (USEPA). 2010. *Regional Screening Levels for Chemical Contaminants at Superfund Sites*. November.



## Tables

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TABLE 1

Groundwater COCs and Key COC Groupings  
 Sitewide Groundwater Performance Monitoring Plan  
 Institute, West Virginia

Analyte Name	Group	USEPA MCLs or RSLs (µg/L)*	USEPA ESL (µg/L)	Groundwater COC Identified in CCR (CH2M HILL 2009a)
<b>Key COC Group 1 - Chlorinated Aliphatic Hydrocarbons</b>				
1,1,2-Trichloroethane	VOC	5**	1200	X
1,1-Dichloroethane	VOC	2.4	47	X
1,1-Dichloroethene	VOC	7**	25	X
1,2-Dichloroethane	VOC	5**	100	X
cis-1,2-Dichloroethene	VOC	70**	--	X
Tetrachloroethene	VOC	5**	111	X
Trichloroethene	VOC	5**	21	X
Vinyl chloride	VOC	2**	930	X
<b>Key COC Group 2 - Petroleum Hydrocarbons</b>				
Benzene	VOC	5**	370	X
Ethylbenzene	VOC	700**	90	X
Toluene	VOC	1000**	2	X
Xylenes	VOC	10000**	13	X
Naphthalene	SVOC	0.14	1.1	X
<b>Key COC Group 3 - Carbon Tetrachloride</b>				
Carbon tetrachloride	VOC	5**	13.3	X
<b>Key COC Group 4 - Chloroform</b>				
Chloroform	VOC	80**	1.8	X
<b>Other Targeted COCs (see Table 6)</b>				
Acetone	VOC	22000	1500	X
Dichlorodifluoromethane	VOC	390	--	X
Trichlorofluoromethane	VOC	1300	--	X
1,4-Dioxane	SVOC	0.067	--	X
bis(2-Chloroethyl)ether	SVOC	0.012	--	X
bis(2-Chloroisopropyl)ether	SVOC	0.32	--	X
bis(2-Ethylhexyl)phthalate	SVOC	6**	16	X
Isophorone	SVOC	71	--	X
Phenol	SVOC	11000	4	
<b>Non-Key COCs</b>				
1,1,2,2-Tetrachloroethane	VOC	0.067	610	X
trans-1,2-Dichloroethene	VOC	100**	--	X
1,2-Dichloropropane	VOC	5**	--	X
1,4-Dichlorobenzene	VOC	75**	26	X
2-Butanone	VOC	7100	14000	X
4-Methyl-2-Pentanone	VOC	2000	170	X
Bromodichloromethane	VOC	80**	--	X
Bromomethane	VOC	8.7	--	X
Carbon Disulfide	VOC	1000	0.92	
Chlorobenzene	VOC	100**	1.3	X
Chloromethane	VOC	190	--	X
Dibromochloromethane	VOC	80**	--	X
Hexachloroethane	VOC	4.8	12	X
Methylene chloride	VOC	5**	98.1	X
Styrene	VOC	100**	72	
2-Methylnaphthalene	SVOC	150	4.7	X
Benzo(b)fluoranthene	SVOC	0.029	--	X

**Notes:**

USEPA = United States Environmental Protection Agency; MCL = Maximum Contaminant Level; RSL = Regional Screening Level; ESL = Ecological Screening Level

COC = Constituent of Concern

CCR = Current Conditions Report

µg/L - micrograms per liter

\* The listed SLs are the MCLs or the USEPA tap water RSLs (USEPA, November 2010) if a constituent does not have an MCL.

\*\* Value is the USEPA MCL.



TABLE 2

Groundwater Monitoring Network  
 Sitewide Groundwater Performance Monitoring Plan  
 Institute, West Virginia

Well ID	Shallow or Deep Aquifer Zone <sup>a</sup>	Screened Lithology	Depth to		Annual Monitoring Activity	Analytical Suites <sup>b</sup>			Sentinel or Perimeter Monitoring Well	Part of Thiessen Well Network
			Top of Screen (feet bgs)	Bottom of Screen (feet bgs)		Site-Specific VOC List	Site-Specific SVOC List			
ENBN-14	Deep	Sand	36	38	Sample+Water Level	X				X
MW-102	Shallow	Sand	23	33	Sample+Water Level	X	X		Perimeter	X
MW-103	Deep	Sand	41	51	Sample+Water Level	X	X		Perimeter	X
MW-104	Shallow	Sand	NA	34*	Water Level					
TW-24	Shallow	Sand	16	26	Water Level					
TW-26	Shallow	Sand	16	26	Sample+Water Level	X			Sentinel	X
TW-27R	NA	Silt/Clay	20	20	Sample+Water Level	X	X			
TW-29	Shallow	Sand	19	29	Water Level					
TW-42	Deep	Sand	43	53	Sample+Water Level	X				X
TW-45	Shallow	Sand	20	30	Sample+Water Level	X				X
TW-46	Deep	Sand	34	44	Sample+Water Level	X				X
TW-50	Deep	Sand	26	36	Water Level					
TW-51	Shallow	Sand	9	19	Water Level					
TW-52A	Shallow	Sand	20	30	Sample+Water Level	X	X		Sentinel	X
TW-52B	Deep	Sand	40	50	Sample+Water Level	X	X		Sentinel	X
TW-53	Deep	Sand	36	46	Sample+Water Level	X			Sentinel	X
TW-54A	Shallow	Sand	25	35	Sample+Water Level	X				X
TW-54B	Deep	Sand	43	53	Sample+Water Level	X				X
TW-55	Deep	Sand	30	40	Sample+Water Level	X				X
TW-56	Deep	Sand	50	60	Sample+Water Level	X				X
TW-57	Deep	Sand	35	45	Sample+Water Level	X				X
TW-58	Shallow	Sand	15	25	Sample+Water Level	X			Sentinel	X
TW-59A	Shallow	Sand	18	28	Sample+Water Level	X				X
TW-59B	Deep	Sand	40	50	Sample+Water Level	X				X
TW-60A	Shallow	Sand	16	26	Sample+Water Level	X	X		Perimeter	X
TW-60B	Deep	Sand	32	42	Sample+Water Level	X	X		Perimeter	X
TW-61	Deep	Sand	40	50	Sample+Water Level	X			Sentinel	X
TW-62A	Shallow	Sand	17	27	Sample+Water Level	X			Sentinel	X
TW-62B	Deep	Sand	40	50	Sample+Water Level	X			Sentinel	X
TW-63A	NA	Silt/Clay	23	33	Sample+Water Level	X	X		Perimeter	X
TW-63B	Deep	Sand	37	47	Sample+Water Level	X	X		Perimeter	X
TW-64	Deep	Sand	41	51	Sample+Water Level	X			Perimeter	X
TW-65A	Shallow	Sand	15	25	Sample+Water Level	X			Perimeter	X
TW-65B	Deep	Sand	45	55	Sample+Water Level	X	X		Perimeter	X
TW-66B	Deep	Sand	33	43	Sample+Water Level	X			Perimeter	X
TW-67B	Deep	Sand	40.5	50.5	Sample+Water Level	X			Perimeter	X



TABLE 2

Groundwater Monitoring Network  
 Sitewide Groundwater Performance Monitoring Plan  
 Institute, West Virginia

Well ID	Shallow or Deep Aquifer Zone <sup>a</sup>	Screened Lithology	Depth to		Annual Monitoring Event Activity	Analytical Suites <sup>b</sup>			Part of Thiessen Well Network
			Top of Screen (feet bgs)	Bottom of Screen (feet bgs)		Site- Specific VOC List	Site- Specific SVOC List	Sentinel or Perimeter Monitoring Well	
VW-11A	Shallow	Sand	16	26	Water Level				
VW-11B	Deep	Sand	45	55	Water Level				
VW-12B	Deep	Sand	43.5	53.5	Water Level				
VW-15A	Shallow	Sand	20	30	Sample+Water Level	X		Perimeter	X
VW-15B	Deep	Sand	39	49	Sample+Water Level	X		Perimeter	X
VW-1A	Shallow	Sand	20	30	Water Level				
VW-1B	Deep	Sand	33	43	Water Level				
VW-2A	Shallow	Sand	10	20	Water Level				
VW-2B	Deep	Sand	40	50	Water Level				
VW-3A	Shallow	Sand	21	31	Sample+Water Level	X		Perimeter	X
VW-3B	Deep	Sand	42	52	Sample+Water Level	X		Perimeter	X
VW-4B	Deep	Sand	40	50	Water Level				
VW-7AB	Shallow	Sand	20	30	Water Level				
VW-9A	Shallow	Sand	18	28	Water Level				
VW-9B	Deep	Sand	48	58	Water Level				
Proposed Well #1	Deep	Sand	TBD	TBD	Sample+Water Level	X			X
Proposed Well #2	Deep	Sand	TBD	TBD	Sample+Water Level	X			X

bgs = below ground surface

NA = not applicable (the well is screened within the silt/clay)

TBD = to be determined

<sup>a</sup> Screened zones: Shallow - to 30 ft-bgs; Deep - 30 ft-bgs +

<sup>b</sup> See Table 3 for site specific lists of volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs)

\* Based on measured total depth.



TABLE 3

Target Analyte List

Sitewide Groundwater Performance Monitoring Plan

Institute, West Virginia

Constituent		Constituent	
Group	Target Analyte List	Group	Target Analyte List
VOCs	1,1,2,2-Tetrachloroethane	SVOCs	1,4-Dioxane
	1,1,2-Trichloroethane		2-Methylnaphthalene
	1,1-Dichloroethane		Benzo(b)fluoranthene
	1,1-Dichloroethene		bis(2-Chloroethyl)ether
	1,2-Dichloroethane		bis(2-Chloroisopropyl)ether
	1,2-Dichloropropane		bis(2-Ethylhexyl)phthalate
	1,4-Dichlorobenzene		Isophorone
	2-Butanone		Naphthalene
	4-Methyl-2-Pentanone		Phenol
	Acetone		
	Benzene		
	Bromodichloromethane		
	Bromomethane		
	Carbon Disulfide		
	Carbon tetrachloride		
	Chlorobenzene		
	Chloroform		
	Chloromethane		
	cis-1,2-Dichloroethene		
	Dibromochloromethane		
	Dichlorodifluoromethane		
	Ethylbenzene		
	Hexachloroethane		
	Methylene chloride		
	Naphthalene		
	Styrene		
	Tetrachloroethene		
	Toluene		
	trans-1,2-Dichloroethene		
	Trichloroethene		
	Trichlorofluoromethane		
	Vinyl chloride		
	Xylenes		

VOC = volatile organic compound

SVOC = semivolatile organic compound





TABLE 4

Required Analytical Method, Sample Containers, Preservation, and Holding Times  
*Sitewide Groundwater Performance Monitoring Plan*  
*Institute, West Virginia*

Preparatory/Analytical						Holding Time <sup>d</sup>
Analyses	Method	Sample Matrix <sup>a</sup>	Container <sup>b</sup>	Quantity	Preservative <sup>c</sup>	
Volatile Organic Compounds	SW8260B	W	40-mL, glass	3	HCl, pH<2, cool to 4°C	14 days
Semivolatile Organic Compounds	SW8270C-Ultra Low	W	950-ml, amber glass	2	cool to 4°C	7 days - extract 40 days - analyze

Source: USEPA SW-846, third edition, Update IV (January 2008).

Notes:

Sample containers and volume requirements will be specified by the analytical laboratory performing the tests.

<sup>a</sup>W = water

<sup>b</sup>All containers will be sealed with Teflon-lined screw caps.

<sup>c</sup>All samples will be stored promptly at 4°C in an insulated chest.

<sup>d</sup>Holding times are from the time of sample collection.



TABLE 5

Perimeter Monitoring Wells - Applicable Screening Criteria for Onsite Containment Performance Metric  
*Sitewide Groundwater Performance Monitoring Plan*  
*Institute, West Virginia*

Well ID	Apply USEPA RSLs to Groundwater		Apply USEPA ESLs to Groundwater		Shallow or Deep Aquifer Zone <sup>a</sup>	Screened Lithology	Depth to Top of Screen (feet bgs)		Depth to Bottom of Screen (feet bgs)	
	Data?		Data?				Screen	(feet bgs)	Screen	(feet bgs)
MW-102	X		X		Shallow	Sand		23		33
MW-103	X		X		Deep	Sand		41		51
TW-60A	X				Shallow	Sand		16		26
TW-60B	X				Deep	Sand		32		42
TW-63A	X		X		NA	Clay/silt		23		33
TW-63B	X		X		Deep	Sand		37		47
TW-64	X		X		Deep	Sand		41		51
TW-65A	X				Shallow	Sand		15		25
TW-65B	X				Deep	Sand		45		55
TW-66B	X		X		Deep	Sand		33		43
TW-67B	X		X		Deep	Sand		40.5		50.5
VW-15A	X		X		Shallow	Sand		20		30
VW-15B	X		X		Deep	Sand		39		49
VW-3A	X		X		Shallow	Sand		21		31
VW-3B	X		X		Deep	Sand		42		52

<sup>a</sup> Screened zones: Shallow = to 30 feet bgs; Deep = 30+ feet bgs

bgs = below ground surface

NA = Not applicable

RSLs = Regional Screening Levels (USEPA 2010)

ESLs = Ecological Screening Levels (USEPA 2006)



TABLE 6

Other Targeted COCs - Applicable Wells to Track Concentration Trends  
 Sidewide Groundwater Performance Monitoring Plan  
 Institute, West Virginia

Well ID	Other Targeted COCs									
	Acetone	Dichloro- difluoro- methane	Trichloro- fluoro- methane	1,4-Dioxane	Bis(2- chloroethyl) ether	Bis(2- chloroiso- propyl) ether	Bis(2- ethylhexyl) phthalate	Isophorone	Phenol	
ENBN-14			X							
MW-102										X
TW-27R	X						X	X		
TW-45		X								
TW-52A					X	X				
TW-52B					X	X				
TW-54B			X							
TW-56		X	X							
TW-57		X	X							
TW-60A				X						
TW-60B				X						
TW-63A										X
TW-63B										X
TW-65B				X						

COC = constituent of concern



## Figures

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Figure 1  
 Facility Location Map  
 Sitewide Groundwater Performance Monitoring Plan  
 Bayer CropScience Institute Facility  
 Institute, West Virginia

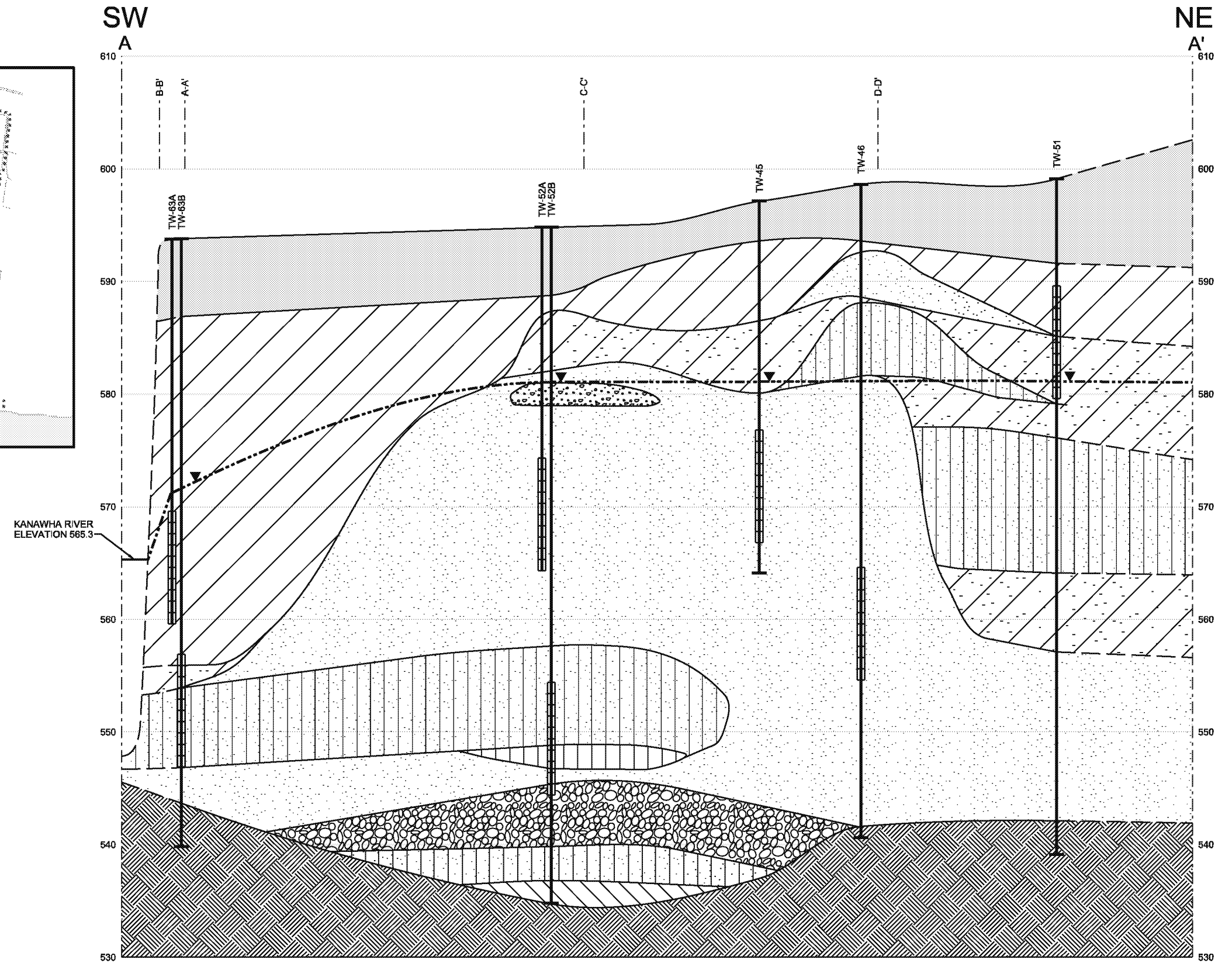
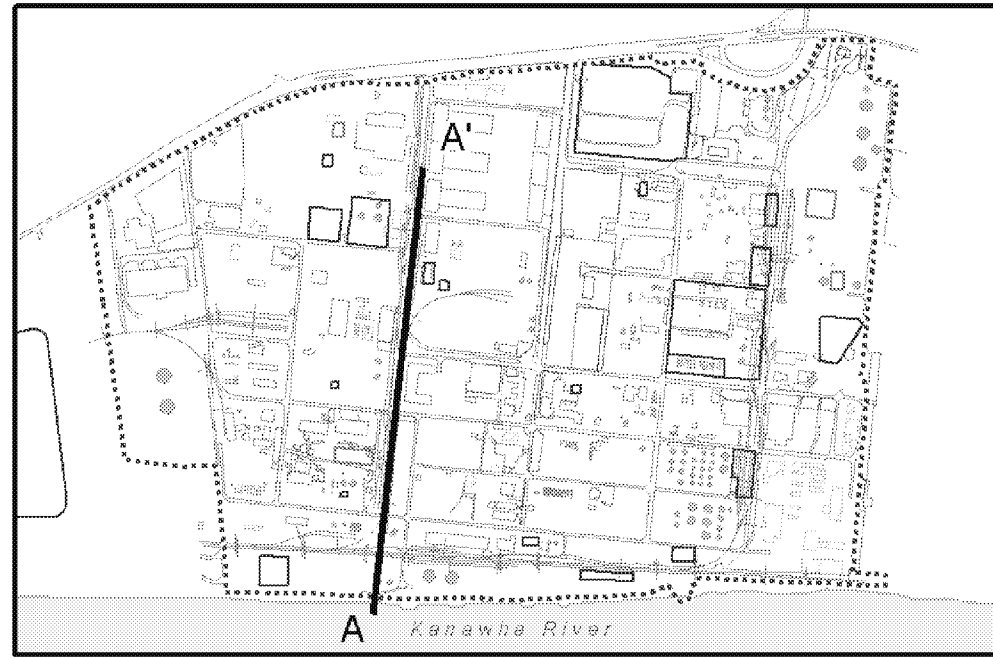






**Figure 2**  
 Interim Remedial Measure Areas  
 Sitewide Groundwater Performance Monitoring Plan  
 Bayer CropScience Institute Facility  
 Institute, West Virginia





# LEGEND

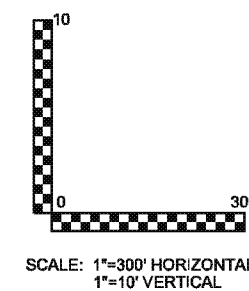
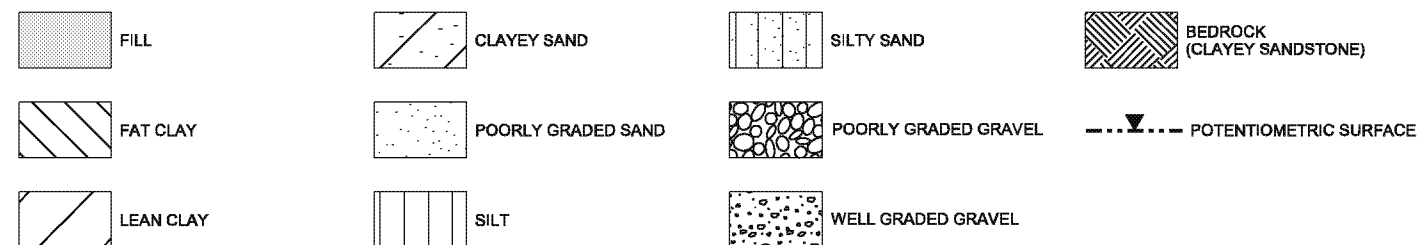


Figure 3  
Geological Cross Section A-A'  
Sitewide Groundwater Performance Monitoring Plan  
Bayer CropScience Institute Facility  
Institute, West Virginia





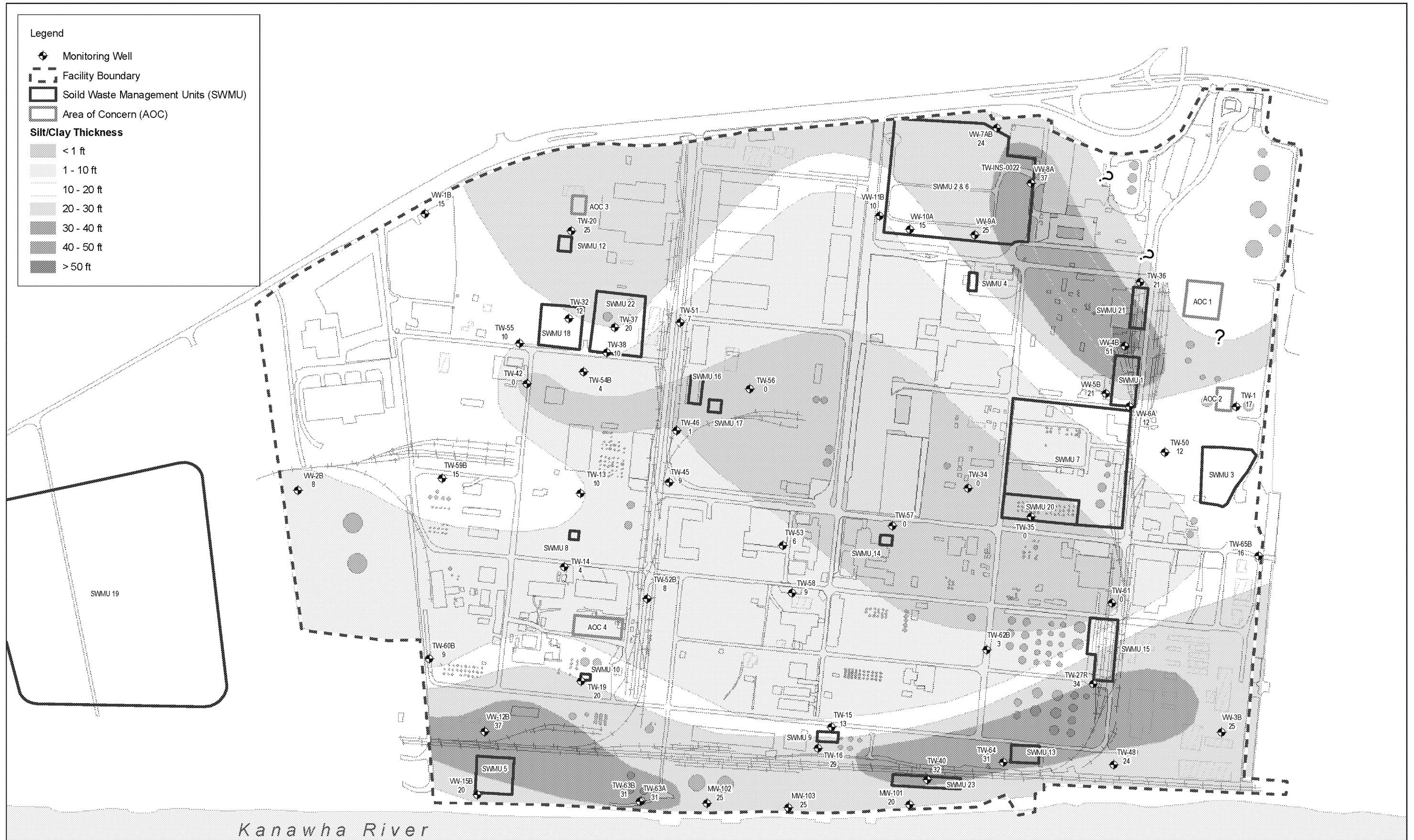


Figure 4  
Silt/Clay Thickness  
Sitewide Groundwater Performance Monitoring Plan  
Bayer CropScience Institute Facility  
Institute, West Virginia

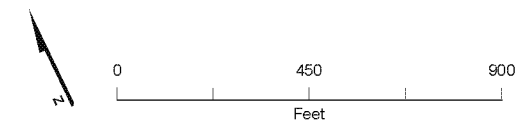
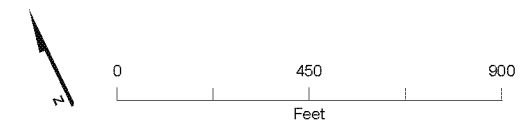








Figure 5  
Saturated Permeable Aquifer Thickness  
Sitewide Groundwater Performance Monitoring Plan  
Bayer CropScience Institute Facility  
Institute, West Virginia





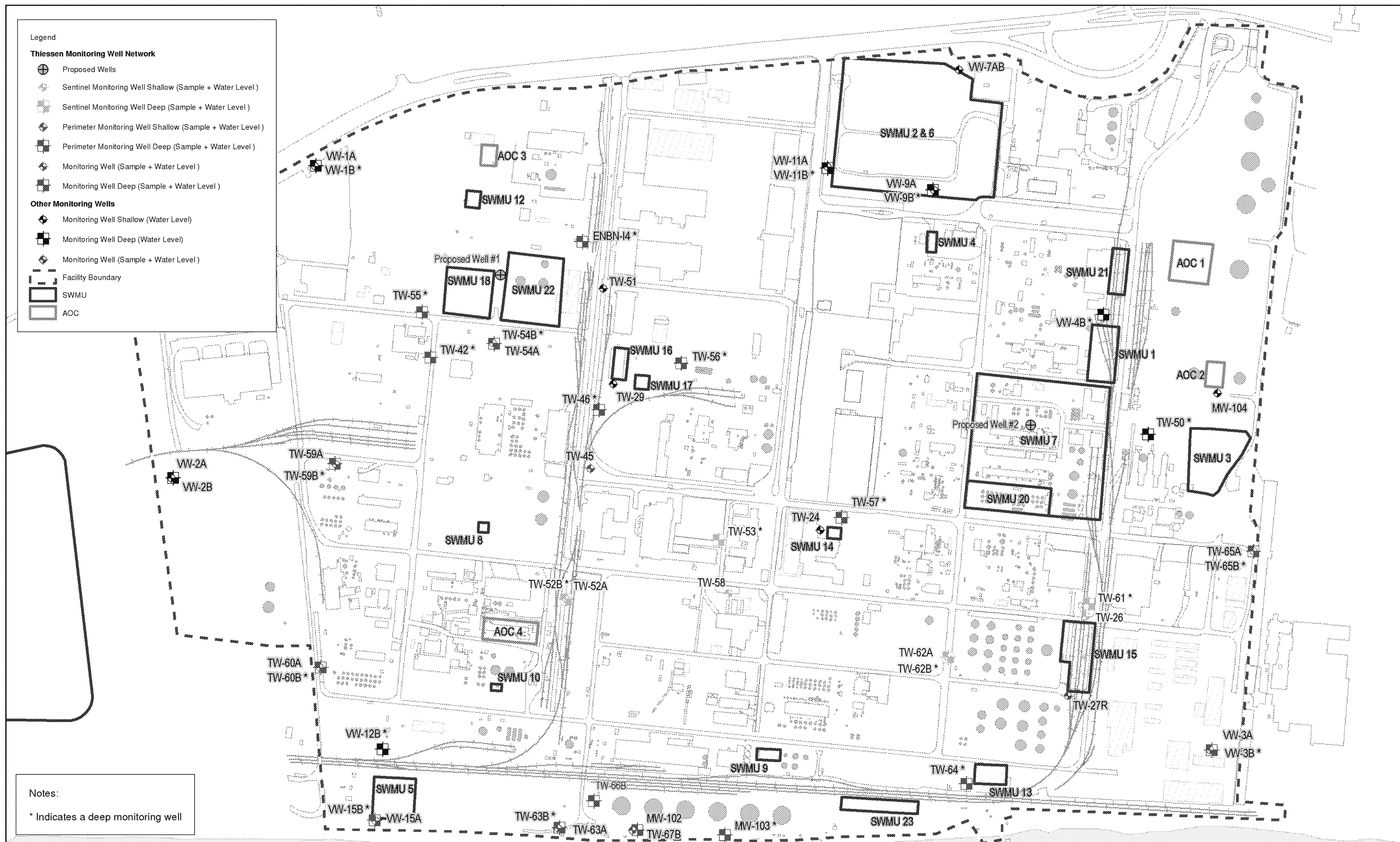


Figure 6  
Optimized Groundwater Monitoring Well Network  
Sitewide Groundwater Performance Monitoring Plan  
Bayer CropScience Institute Facility  
Institute, West Virginia



**Appendix A**  
**Thiessen Polygon Method Background Data**

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TABLE A-1

Thiessen Baseline and Optimized Monitoring Well Networks  
 Sitewide Groundwater Performance Monitoring Plan  
 Institute, West Virginia

Part of 2009 Network <sup>1</sup> ?	Baseline Thiessen Network	Optimized Thiessen Network
	Well ID	Well ID
x	ENBC-I3	
x	ENBN-I4	ENBN-I4
x	MW-101	
x	MW-102	MW-102
	TW-67B	TW-67B
x	MW-103	MW-103
	MW-104	
x	TW-07	
	TW-11	
	TW-12	
x	TW-15	
	TW-18	
	TW-22	
x	TW-23	
x	TW-64	TW-64
x	TW-26	TW-26
x	TW-61	TW-61
x	TW-27R	
	TW-29	
x	TW-42	TW-42
x	TW-45	TW-45
	TW-46	TW-46
x	TW-48	
	TW-50	
	TW-51	
x	TW-52A	TW-52A
x	TW-52B	TW-52B
x	TW-53	TW-53
x	TW-54A	TW-54A
x	TW-54B	TW-54B
x	TW-55	TW-55
x	TW-56	TW-56
x	TW-57	TW-57
x	TW-58	TW-58
x	TW-59A	TW-59A
x	TW-59B	TW-59B
x	TW-60A	TW-60A
x	TW-60B	TW-60B
x	TW-62A	TW-62A
x	TW-62B	TW-62B
x	TW-63A	TW-63A
x	TW-63B	TW-63B
x	TW-65A	TW-65A
x	TW-65B	TW-65B
	TW-66B	TW-66B
x	VW-15A	VW-15A
x	VW-15B	VW-15B
x	VW-2A	
x	VW-2B	
x	VW-3A	VW-3A
x	VW-3B	VW-3B
	VW-4B	
	VW-9A	
		Proposed Well #1
		Proposed Well #2
<b>Total:</b>	<b>53 wells</b>	<b>36 Wells</b>

**Notes:**

\*Proposed monitoring well

Orange and yellow shading indicate well pairs

<sup>1</sup> 2009 Groundwater Monitoring Plan (CH2M HILL 2009a)





TABLE A-2  
Information Used to Derive Aquifer Thickness for Thiessen Monitoring Well Network  
Sitewide Groundwater Performance Monitoring Plan  
Institute, West Virginia

		Lithologic Information <sup>3</sup>																			A +		B		= C				
Thiessen Network Well Pair	Well Location ID	Baseline Thiessen Well Network	Optimized Thiessen Well Network	Depth to top of Screen (ft-bgs)	Depth to Bottom of Screen (ft-bgs)	Screened Zone <sup>1</sup>	Lithology of Well Screen Interval	Casing Elevation (feet amsl)	Ground Surface Elevation (feet amsl)	Northing	Easting	Ground Surface (ft-bgs)	Depth to Bottom of Fill/Upper Unit (ft-bgs)	Depth to Top of Clay/Silt (ft-bgs)	Depth to Bottom of Clay/Silt (ft-bgs)	Silt/Clay Thickness (ft)	Top of Sand/Silty Sand Aquifer (ft-bgs)	Top of Bedrock (ft-bgs)	Average 2009 Water Level (ft-bgs) <sup>2</sup>	Average 2009 Ground Water Elevation (ft-msl)	Depth to Bottom of Clay/Silt (ft-bgs)	Top of Permeable Soils Below Water Table (ft-bgs)	Estimated Top of Bedrock (ft-bgs) <sup>3</sup>	Permeable Soils Below Water Table (ft thick)	Thick-ness of Shallow Aquifer (A)	Thick-ness of Deep Aquifer (B)	Thick-ness of Whole Aquifer (C)	Thick-ness Assigned to Thiessen Polygon	Comments
	ENBC-13	x		35.0	37.0	Deep	Sand	600.44	599.59	505327.76	1744888.45	0	NA	NA	NA	NA	NA	NA	17.94	581.64	NA	17	57	40			40.0	10.0	No information available regarding thickness of aquifer impact - applied a portion of aquifer (10 ft)
	ENBN-14	x	x	36.0	38.0	Deep	Sand	601.02	600.26	505721.87	1745217.24	0	NA	NA	NA	NA	NA	NA	18.55	581.71	NA	21	57	36			36.0	10.0	No information available regarding thickness of aquifer impact - applied a portion of aquifer (10 ft)
MW-102	MW-101	x		22.0	32.0	Shallow	Silt/clay	594.49	592.02	502884.93	1745234.16	0	0	0	30	20 (see comment)	30	NA	11.25	580.76	30	30	50	20	0.0	20.0	20.0	0.0	Well goes dry during low-flow purging; screened in sands within thick silt/clay layer, which do not appear to be connected to the main aquifer; 10-ft of sand/silty sand within thick layer of silt/clay was removed from total silt/clay thickness
	MW-102	x	x	23.0	33.0	Shallow	Sand	595.18	592.79	503311.45	1744335.49	0	0	0	25	25	25	NA	13.16	579.63	25	25	51	26	10.0		26.0	10.0	Split aquifer thickness with TW-67B
	TW-67B	x	x	40.5	50.5	Deep	Sand	592.29	592.41	503303.03	1744352.92	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	25	51	26		16.0	26.0	16.0	Split aquifer thickness with MW-102
MW-103	x	x		41.0	51.0	Deep	Sand	594.50	592.00	503121.89	1744689.64	0	0	0	35	25 (see comment)	35	NA	24.21	567.79	35	35	50	15			15.0	10.0	10-ft of sand/silty sand within thick layer of silt/clay - removed from total silt/clay thickness
MW-104	x			24.0	34.0	Shallow	Sand	596.40	597.13	503956.07	1747447.44	0	NA	NA	NA	NA	NA	NA	16.16	580.97	NA	20	56	36			36.0	18.0	MIP in area (TW-50A and TW-50B) looks clean in deep aquifer zone, therefore no data gap in deep aquifer zone
TW-7	x			15.0	25.0	Shallow	Sand	596.84	597.56	504174.67	1746649.53	0	NA	NA	NA	NA	NA	NA	17.18	580.37	NA	21	56	35			35.0	9.0	No deep aquifer zone MW in area - data gap (MIP-07-1 to the north showed some impact 30- 34ft CT = 140 ppb). Assigned 5 additional feet below bottom of screen.
TW-11	x			15.0	25.0	Shallow	Sand	597.66	598.21	504250.11	1746701.41	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	21	56	35			35.0	9.0	Same as TW-7 (located very close to each other)
TW-12	x			15.0	25.0	Shallow	Sand	598.53	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	21	56	35			35.0	9.0	Same as TW-7 (located very close to each other)
TW-15	x			16.0	26.0	Shallow	Silt/clay	591.79	591.97	503391.81	1745047.06	0	7	7	20	13	20	NA	11.42	580.55	20	20	55	35	0.0	35.0	35.0	0.0	Well goes dry; MIP-09-1 indicates clean conditions below screened interval
TW-18	x			10.0	20.0	Shallow	Sand	592.51	592.74	504282.34	1744181.72	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	18	58	40			40.0	7.0	Assigned 5 additional feet below bottom of screen.
TW-22	x			11.0	21.0	Shallow	Silt/clay	593.72	593.79	502875.06	1745936.36	0	NA	NA	NA	NA	NA	NA	4.91	588.87	NA	35	54	19	0.0	19.0	19.0	0.0	
TW-23	x			17.0	27.0	Shallow	Silt/clay	593.18	593.49	502837.04	1745781.94	0	NA	NA	NA	NA	NA	NA	13.74	579.76	NA	33	54	21	0.0		19.0	0.0	
TW-24	x	x		41.0	51.0	Deep	Sand	592.82	593.08	502878.98	1745737.40	0	4	4	35	31	35	54	17.55	575.53	35	35	54	19		19.0	19.0	19.0	Set in middle of sand layer - apply whole aquifer thickness
TW-26	x	x		16.0	26.0	Shallow	Sand	595.10	595.64	503320.69	1746517.81	0	NA	NA	NA	NA	NA	NA	16.29	579.34	NA	16	55	39	17.0		39.0	17.0	Split aquifer thickness with TW-61 (well pair)
TW-61	x	x		40.0	50.0	Deep	Sand	594.93	595.16	503361.71	1746551.64	0	7	7	7	0	7	55	15.87	579.29	7	15.87	55	39		22.0	39.0	22.0	Split aquifer thickness with TW-26 (well pair)
TW-27R	x			20.0	30.0	Shallow	Silt/clay	595.62	596.07	503040.87	1746300.84	0	1	1	35	34	NA	NA	19.55	576.53	35	35	55	20	0.0		20.0	0.0	Not screened in aquifer zone, but very impacted (acetone). Clay unit thickness unknown; bottom estimated based on CCR Cross-section G-G'
TW-29	x			19.0	29.0	Shallow	Sand	599.44	599.81	505105.17	1745078.24	0	NA	NA	NA	NA	NA	NA	18.48	581.33	NA	17	57	40			40.0	15.0	Near TW-46 (deep well, but not a pair). Assigned 5 ft below bottom of screen.
TW-42	x	x		43.0	53.0	Deep	Sand	597.10	597.63	505545.90	1744404.16	0	3	3	3	0	3	NA	16.02	581.61	3	16.02	59	43			43.0	15.0	Assigned 5-ft above top of screen; MIP TW-43A indicates cleaner (although still impacted) conditions aquifer above this well.
TW-45	x	x		20.0	30.0	Shallow	Sand	596.78	597.14	504813.87	1744834.10	0	2	2	11	9	11	NA	15.62	581.52	11	15.62	57	41			41.0	20.0	Assigned 5-ft above top and below bottom of screen; MIP TW-45 and GW grab samples indicate cleaner conditions below well screen (but still slightly impacted)
TW-46	x	x		34.0	44.0	Deep	Sand	598.18	598.55	505028.42	1744973.64	0	5	5	6	1	6	57	17.00	581.55	6	17	57	40			40.0	15.0	Near TW-29 (but not a pair). GW grabs in area indicate that deeper contamination could be present, therefore bottom 10-ft of aquifer was not assigned to this well
TW-48	x			12.0	22.0	Shallow	Silt/clay	594.52	594.84	502639.72	1746224.03	0	5	5	33.5	23.5 (see comment)	33.5	53	14.20	580.64	33.5	33.5	53	20	0.0	20.0	20.0	0.0	5-ft of sand/silty sand within thick layer of silt/clay - removed from total silt/clay thickness
TW-50	x			26.0	36.0	Deep	Sand	597.86	598.32	503921.73	1747097.08	0	5	5	17	12	17	56	18.14	580.18	17	18.14	56	38			38.0	20.0	Assigned 5-ft above and below well screen.
TW-51	x			9.0	19.0	Shallow	Sand	598.79	599.14	505500.37	1745214.01	0	7.5	7.5	14	6.5	14	57	17.54	581.59	14	17.54	57	39			39.0	7.0	Assigned 5-ft below bottom of screen and 2-ft screened in aquifer.
TW-52A	x	x		20.0	30.0	Shallow	Sand	594.51	594.96	504346.83	1744497.61	0	2	2	10	8	10	58	13.51	581.45	10	13.51	58	44	21.0		44	21	Split aquifer thickness with TW-52B (well pair)
TW-52B	x	x		40.0	50.0	Deep	Sand	594.40	594.80	504342.82	1744494.69	0	2	2	10	8	10	58	13.34	581.46	10	13.34	58	45		23.0	44	23	Split aquifer thickness with TW-52A (well pair)
TW-53	x	x		36.0	46.0	Deep	Sand	595.70	595.26	504297.14	1745206.81	0	1	1	7	6	7	56	13.12	582.14	7	13.12	56	43			43.0	20.0	Assigned 5-ft above and below well screen; screened in most impacted zone based on MIP log DN6B
TW-54A	x	x		25.0	35.0	Shallow	Sand	598.41	598.81	505488.45	1744679.56	0	1	1	5	4	5	58	17.13	581.68	5	17.13	58	41	22.0		41.0	22.0	Split aquifer thickness with TW-54B (well pair)
TW-54B	x	x		43.0	53.0	Deep	Sand	598.54	598.87	505482.59	1744681.05	0	1	1	5	4	5	58	17.22	581.65	5	17.22	58	41		19.0	41.0	19.0	Split aquifer thickness with TW-54A (well pair)
TW-55	x	x		30.0	40.0	Deep	Sand	598.21	598.85	505740.12	1744456.02	0	6	6	16	10	16	59	17.12	581.73	16	17.12	59	42			42.0	20.0	Assigned 5-ft above and below well screen; nearby TW-42 v. impacted in deeper zone
TW-56	x	x		50.0	60.0	Deep	Sand	599.79	600.03	505060.67	1745383.84	0	4	4	4	0	4	61	18.60	581.44	4	18.6	61	42			42.0	17.0	Assigned 5-ft above and 2-ft below well screen tp bedrock; shallow zone is cleaner
TW-57	x	x		35.0	45.0	Deep	Sand	595.44	595.68	504158.65	1745734.04	0	5	5	5	0	5	56	14.75	580.93	5	14.75	56	41			41.0	20.0	Assigned 5-ft above and below well screen; cleaner above, may be more impacted below (installed between MIP DN7B and DN7C)
TW-58	x	x		15.0	25.0	Shallow	Sand	594.10	594.36	504068.14	1745150.28	0	1	1	10	9	10	55	13.20	581.15	10	13.2	55	42			42.0	17.0	Assigned 2-ft above and 5-ft below well screen; MIP DN6C and GW grab indicate cleaner deeper at this location (GW grab shallow at DN6C was v. high for ethylbenzene, but not showing up in MW samples)
TW-59A	x	x		18.0	28.0	Shallow	Sand	595.20	595.66	505300.94	1743836.56	0	1	1	16	15	16	56	14.00	581.66	16	16	56	40	18.0		40.0	18.0	Split aquifer thickness with TW-59B (well pair)
TW-59B	x	x		40.0																									



TABLE A-2  
Information Used to Derive Aquifer Thickness for Thiessen Monitoring Well Network  
Sitewide Groundwater Performance Monitoring Plan  
Institute, West Virginia

		Lithologic Information <sup>3</sup>																	A +			B		= C					
Thiessen Network Well Pair	Well Location ID	Baseline Thiessen Well Network	Optimized Thiessen Well Network	Depth to top of Screen (ft-bgs)	Depth to Bottom of Screen (ft-bgs)	Screened Zone <sup>1</sup>	Lithology of Well Screen Interval	Casing Elevation (feet amsl)	Ground Surface Elevation (feet amsl)	Northing	Eastings	Ground Surface (ft-bgs)	Depth to Bottom of Fill/Upper Unit (ft-bgs)	Depth to Top of Clay/Silt (ft-bgs)	Depth to Bottom of Clay/Silt (ft-bgs)	Silt/Clay Thickness (ft)	Top of Sand/Silty Sand Aquifer (ft-bgs)	Top of Bedrock (ft-bgs)	Average 2009 Water Level (ft-bgs) <sup>2</sup>	Average 2009 Ground Water Elevation (ft-msl)	Depth to Bottom of Clay/Silt (ft-bgs)	Top of Permeable Soils Below Water Table (ft-bgs)	Estimated Top of Bedrock (ft-bgs) <sup>3</sup>	Permeable Soils Below Water Table (ft thick)	Thick-ness of Shallow Aquifer (A)	Thick-ness of Deep Aquifer (B)	Thick-ness of Whole Aquifer (C)	Thick-ness Assigned to Thiessen Polygon	Comments
TW-63A	TW-63A	x	x	23.0	33.0	Shallow	Silt/clay	592.89	593.60	503457.63	1744043.94	0	7	7	38	31	38	50	23.31	570.29	38	38	50	12	0.0		0.0	1.0	Not screened in the sand aquifer zone, but very impacted (benzene). Assigned 1 ft so that some mass will show up in Thiessen network
	TW-63B	x	x	37.0	47.0	Deep	Sand	592.89	593.85	503455.49	1744050.89	0	7	7	38	31	38	50	23.86	569.99	38	38	50	12		12.0	12.0	12.0	Well screen in almost entire sand aquifer zone (very thin at this location) - assigned entire aquifer thickness
TW-65A	TW-65A	x	x	15.0	25.0	Shallow	Sand	595.32	595.46	503268.59	1747299.50	0	6	6	22	16	22	57	17.16	578.30	22	22	57	35	13.0		35.0	13.0	Split aquifer thickness with TW-65B (well pair)
	TW-65B	x	x	45.0	55.0	Deep	Sand	595.30	595.43	503266.54	1747298.29	0	6	6	22	16	22	57	17.35	578.08	22	22	57	35		22.0	35.0	22.0	Split aquifer thickness with TW-65A (well pair)
VW-2A	TW-66B	x	x	33.0	43.0	Deep	Sand	593.83	593.94	503497.73	1744234.51	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12			12.0	12.0	Assign 12 feet based on cross-section B-B' in INS-0005 Tech Memo	
	VW-2A	x		10.0	20.0	Shallow	Sand	594.87	593.00	505548.47	1743161.64	0	6	6	14	8	14	na	12.18	580.81	14	14	54	40	16.0		40.0	16.0	Split aquifer thickness with VW-2B (well pair)
	VW-2B	x		40.0	50.0	Deep	Sand	595.16	592.99	505546.76	1743167.47	0	6	6	14	8	14	na	11.37	581.62	14	14	54	40		24.0	40.0	24.0	Split aquifer thickness with VW-2A (well pair)
VW-3A																25 (see comment)	35	54	18.54	575.79	35	35	54	19	5.0		19.0	5.0	Split aquifer thickness with VW-3B (well pair); did not include lower 5-ft of silt/clay at base of well screen in the total silt/clay thickness. Sand within VW-3A appears to be connected to main aquifer.
	VW-3B	x	x	42.0	52.0	Deep	Sand	595.59	595.76	502560.61	1746768.24	0	5	5	35	30	35	54	21.27	574.49	35	35	54	19		19.0	19.0	19.0	Split aquifer thickness with VW-3A (well pair)
	VW-4B	x		40.0	50.0	Deep	Silt/clay	596.61	597.54	504475.81	1747140.32	0	1	1	52	51	52	56	16.14	581.40	52	52	56	4	0.0	4.0	4.0	0.0	
VW-15A	VW-9A	x		18.0	28.0	Shallow	Sand	601.20	599.64	505278.64	1746701.01	0	0	0	25	25	25	na	18.20	581.44	25	25	58.5	34			34.0	8.0	Assigned sand layer within screened interval (3-ft) plus 5-ft below screen.
	VW-15A	x	x	20.0	30.0	Shallow	Sand	594.15	592.45	503821.18	1743338.45	0	5	5	25	20	25	na	15.06	577.39	25	25	52	27	10.0		27.0	10.0	Split aquifer thickness with VW-15B (well pair)
	VW-15B	x	x	39.0	49.0	Deep	Sand	593.72	592.49	503824.66	1743333.78	0	5	5	25	20	25	na	19.86	572.63	25	25	52	27		17.0	27.0	17.0	Split aquifer thickness with VW-15A (well pair)

<sup>1</sup> Screened zones: Shallow - to 30 ft-bgs; Deep - 30 ft-bgs +  
<sup>2</sup> Average groundwater elevation from the 2009 Groundwater Monitoring Report (CH2M HILL 2010c)  
<sup>3</sup> Most lithologic information from boring logs. Where necessary, information from adjacent borings or wells was used to determine aquifer thickness. In some cases, established cross-sections (e.g., from CCR [CH2M HILL 2009b]) were used to estimate aquifer thickness



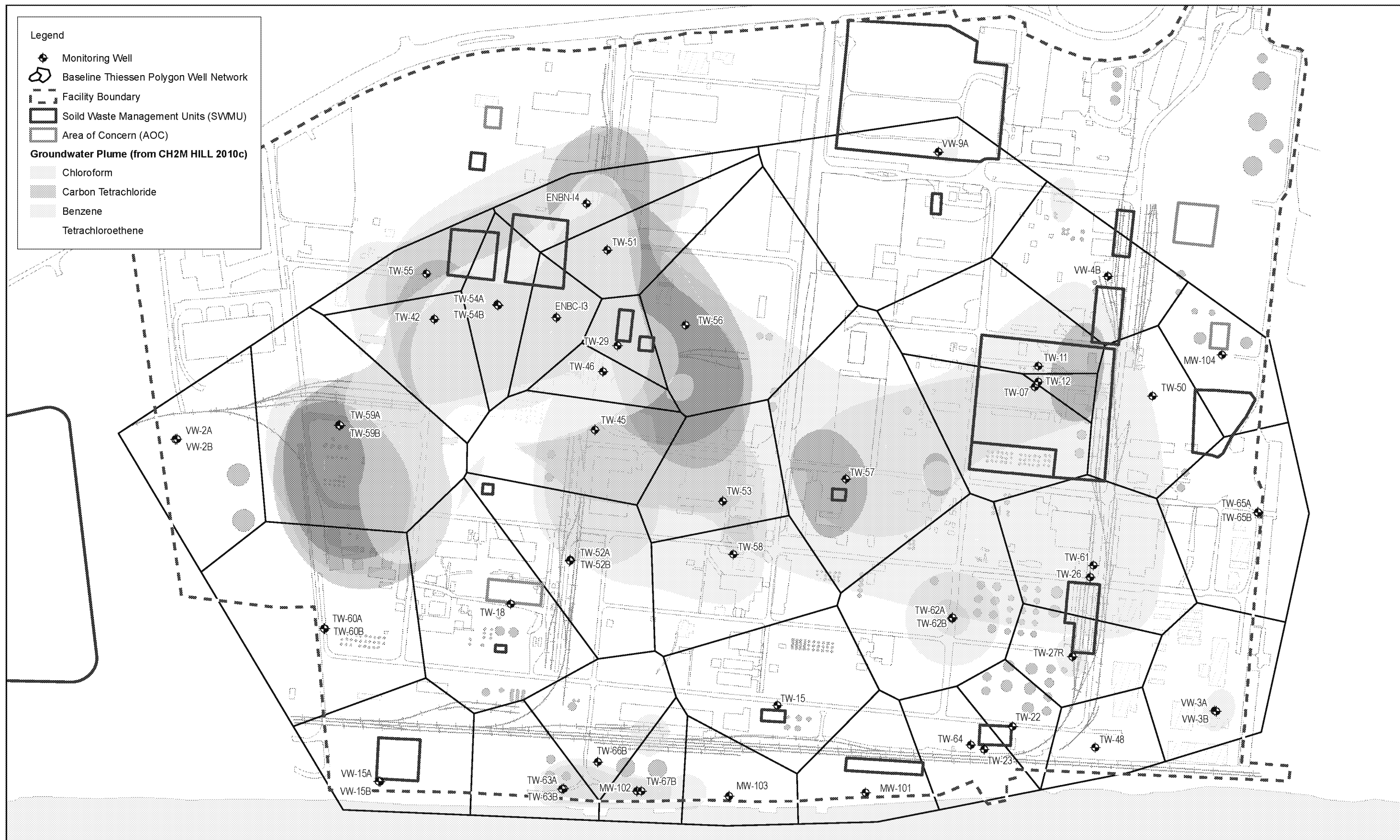


Figure A-1  
Baseline Thiessen Polygon Monitoring Well Network  
Sitewide Groundwater Performance Monitoring Plan  
Bayer CropScience Institute Facility  
Institute, West Virginia



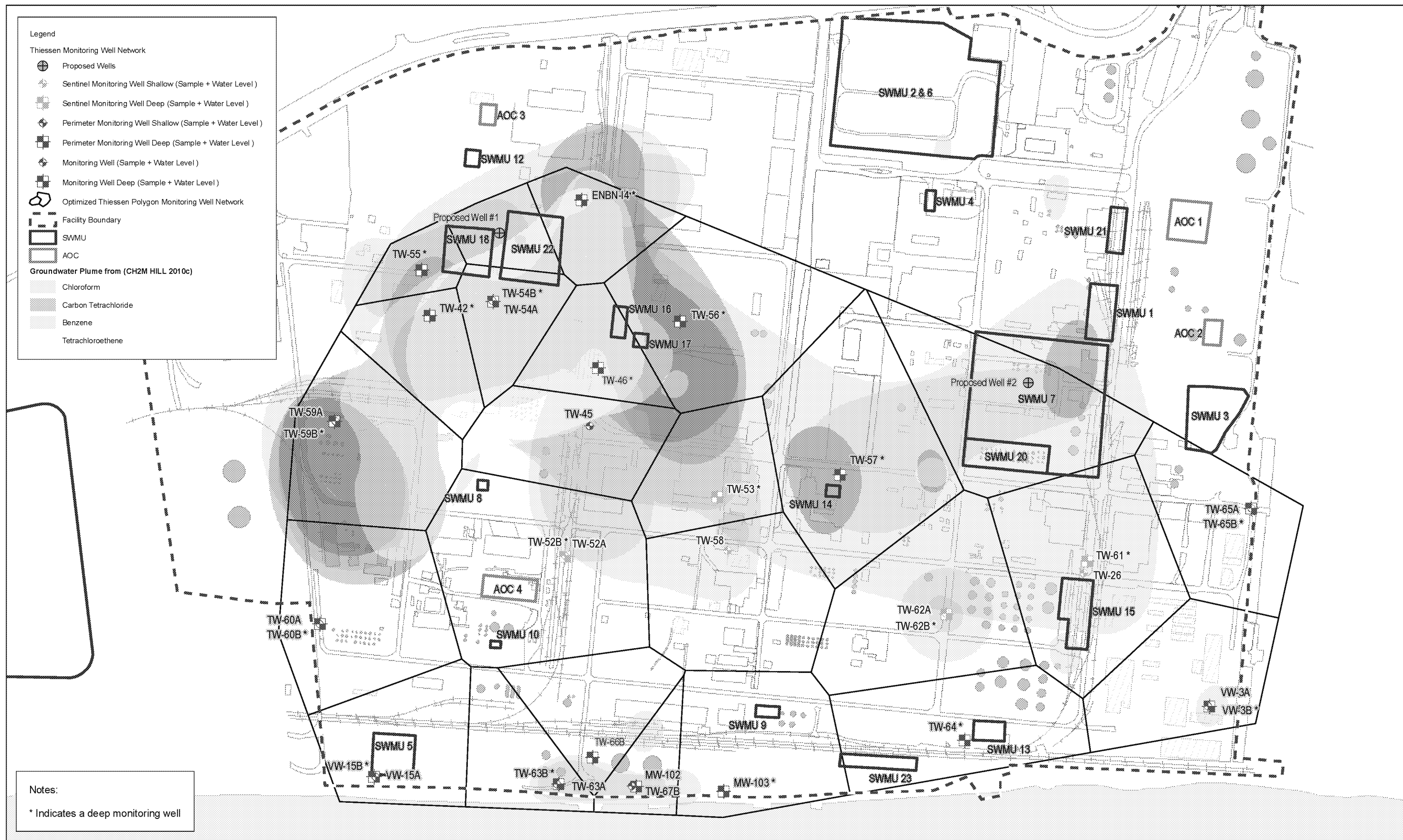
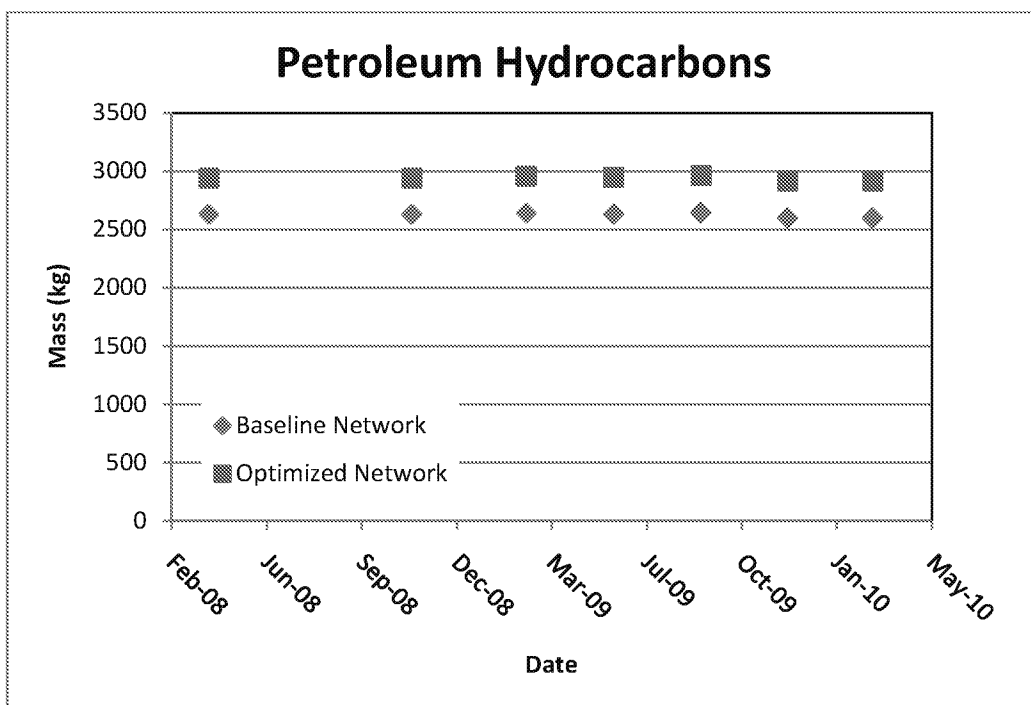
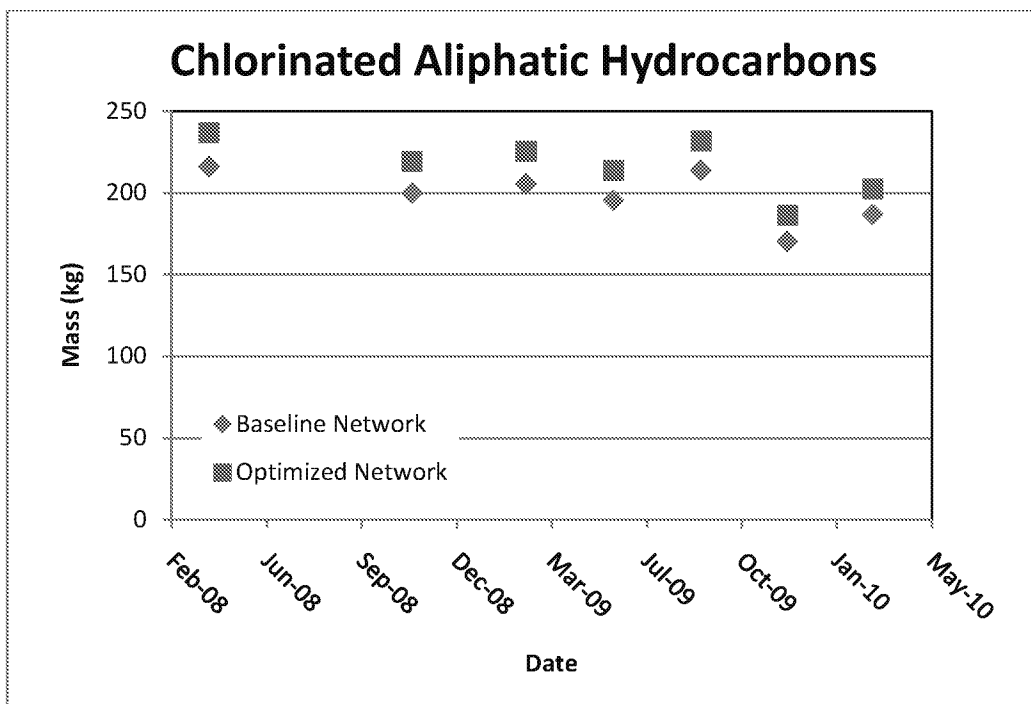


Figure A-2  
 Optimized Thiessen Polygon Monitoring Well Network  
 Sitewide Groundwater Performance Monitoring Plan  
 Bayer CropScience Institute Facility  
 Institute, West Virginia

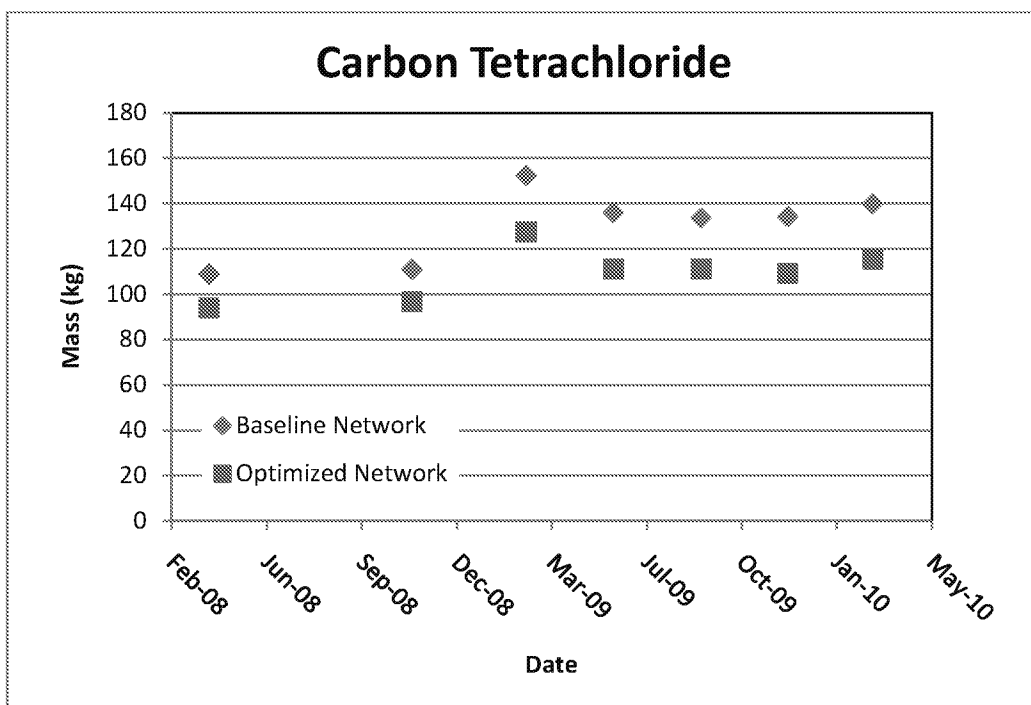
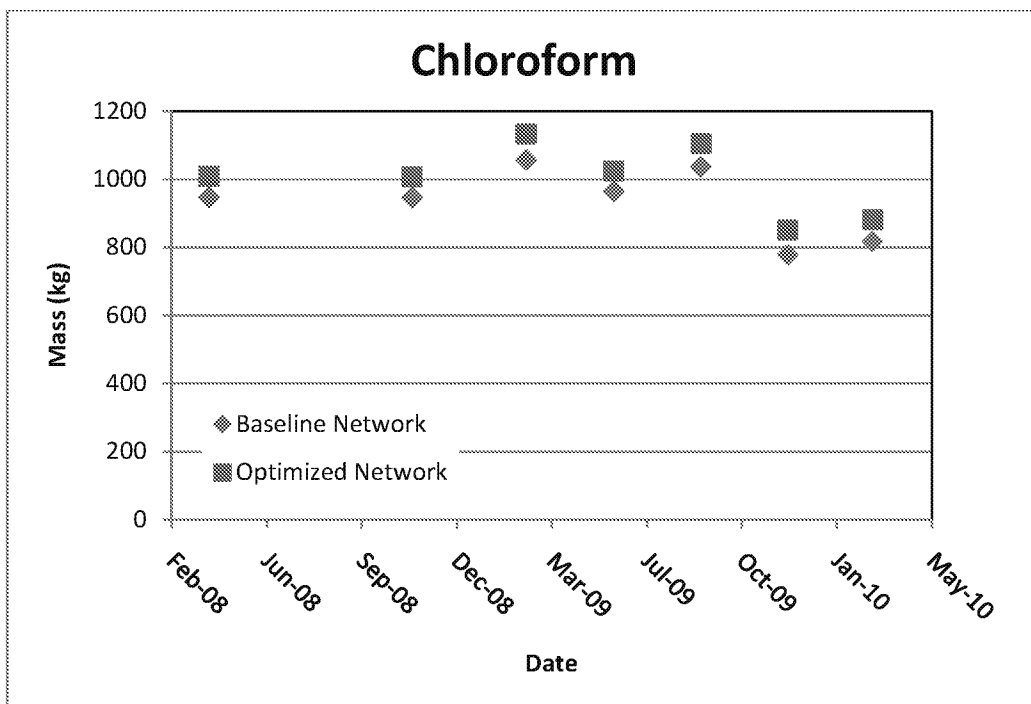






**Figure A-3**  
 Thiessen Baseline and Optimized Monitoring Well Network Mass Comparison -  
 Chlorinated Aliphatic Hydrocarbons and Petroleum Hydrocarbons  
*Sitewide Groundwater Performance Monitoring Plan*  
*Institute, West Virginia*





**Figure A-4**  
Thiessen Baseline and Optimized Monitoring Well Network Mass Comparison -  
Chloroform and Carbon Tetrachloride  
*Sitewide Groundwater Performance Monitoring Plan*  
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## **Appendix B**

# **Seasonality Evaluation**

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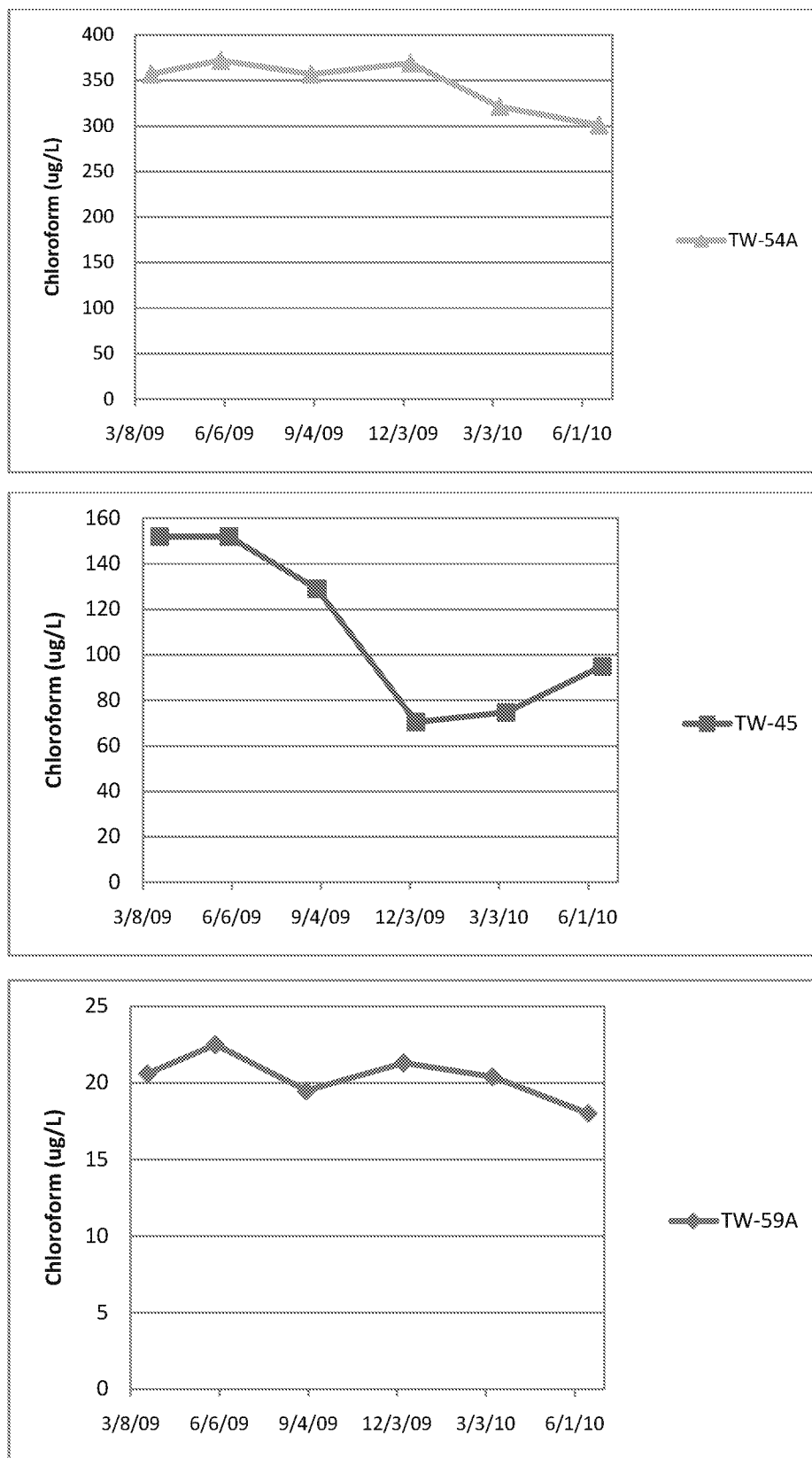


Figure B-1  
Temporal Concentrations of Chloroform, Shallow Aquifer Zone  
Sitewide Groundwater Performance Monitoring Plan  
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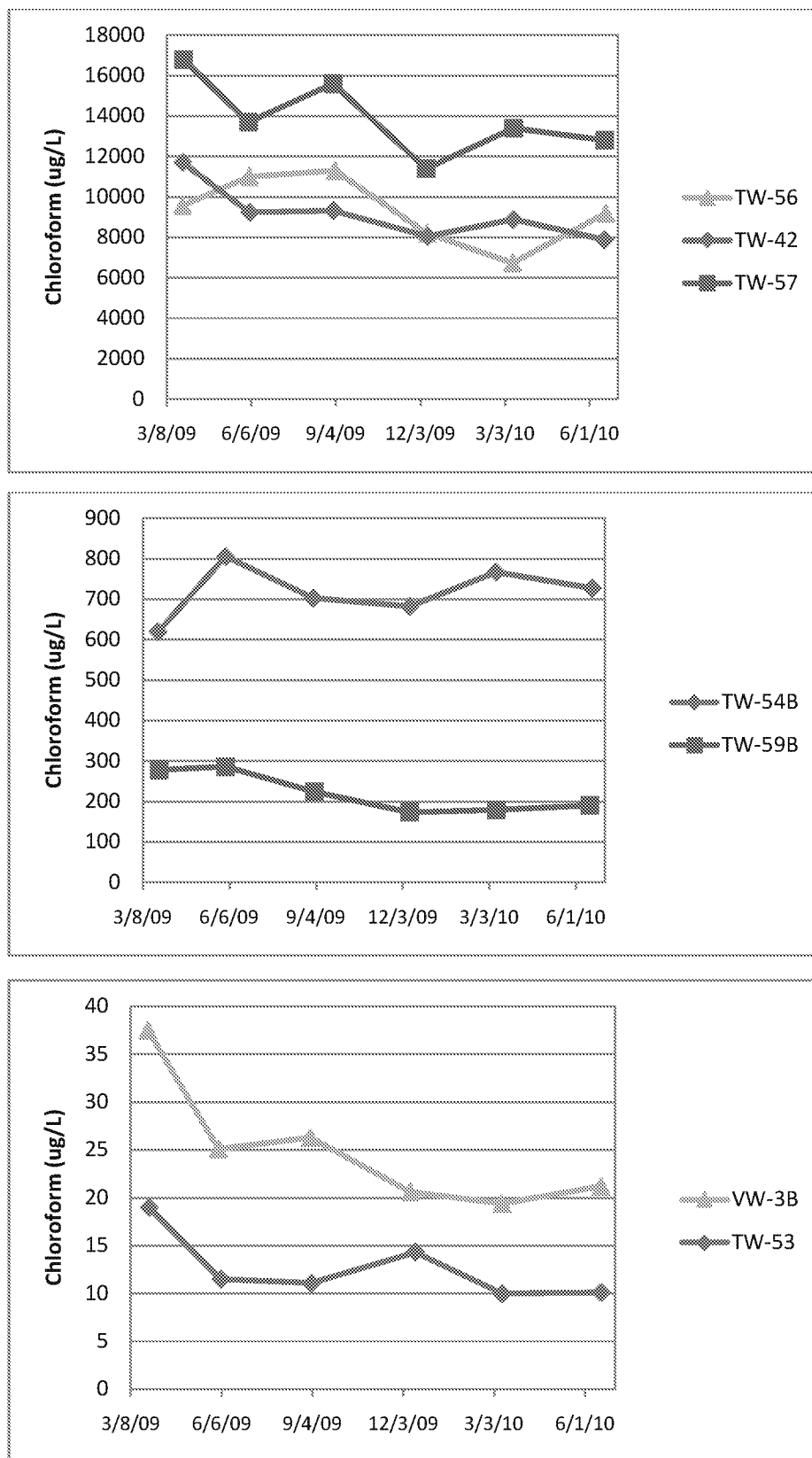
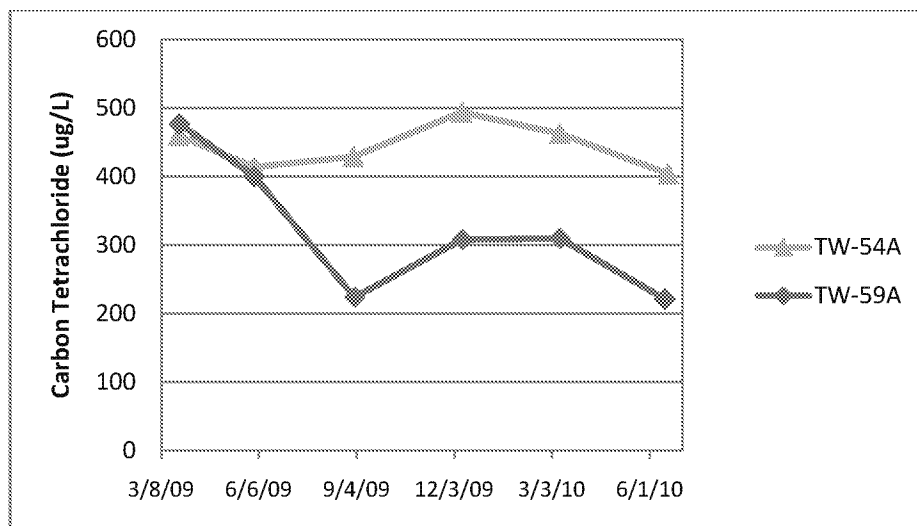


Figure B-2  
Temporal Concentrations of Chloroform, Deep Aquifer Zone  
Sitewide Groundwater Performance Monitoring Plan  
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**Figure B-3**  
Temporal Concentrations of Carbon Tetrachloride, Shallow Aquifer Zone  
*Sitewide Groundwater Performance Monitoring Plan*  
*Institute, West Virginia*



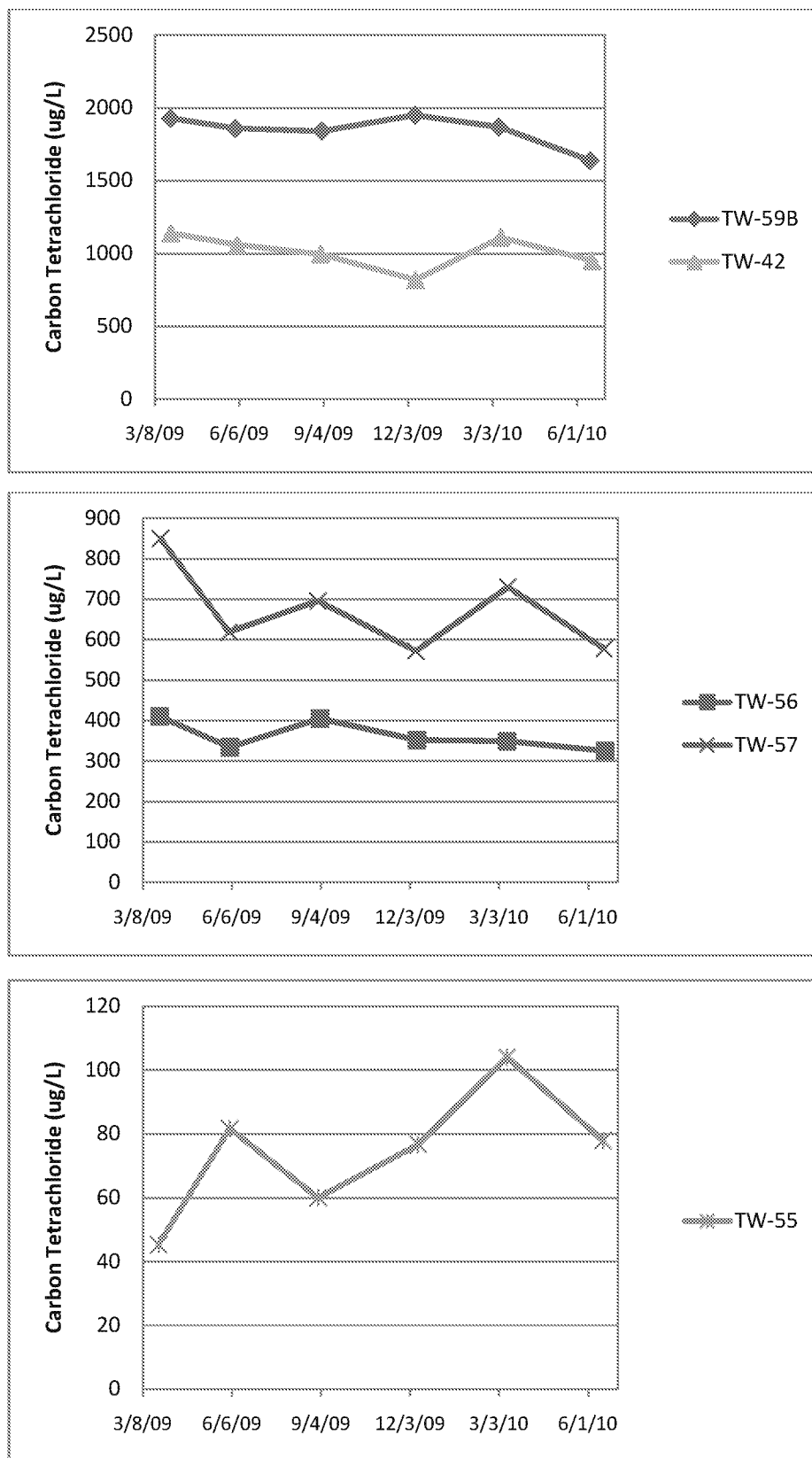


Figure B-4  
Temporal Concentrations of Carbon Tetrachloride, Deep Aquifer Zone  
Sitewide Groundwater Performance Monitoring Plan  
Institute, West Virginia



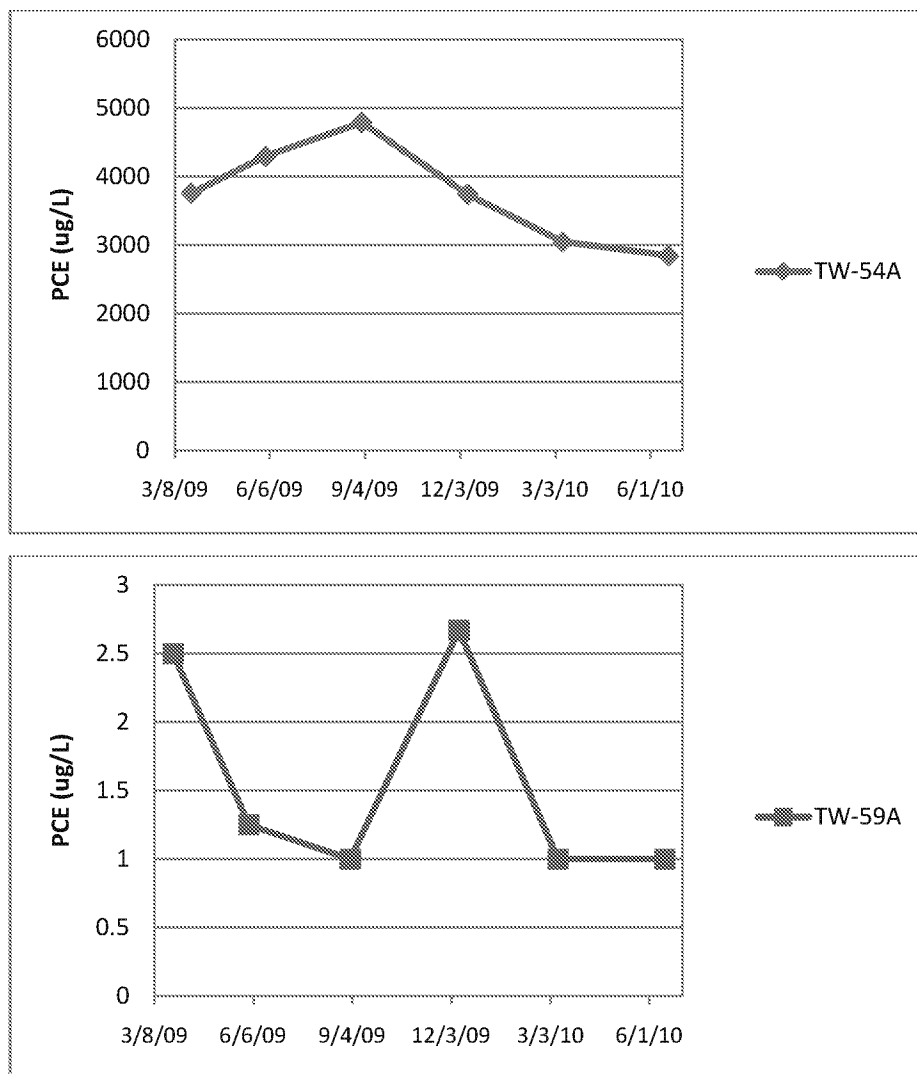


Figure B-5  
Temporal Concentrations of PCE, Shallow Aquifer Zone  
Sitewide Groundwater Performance Monitoring Plan  
Institute, West Virginia





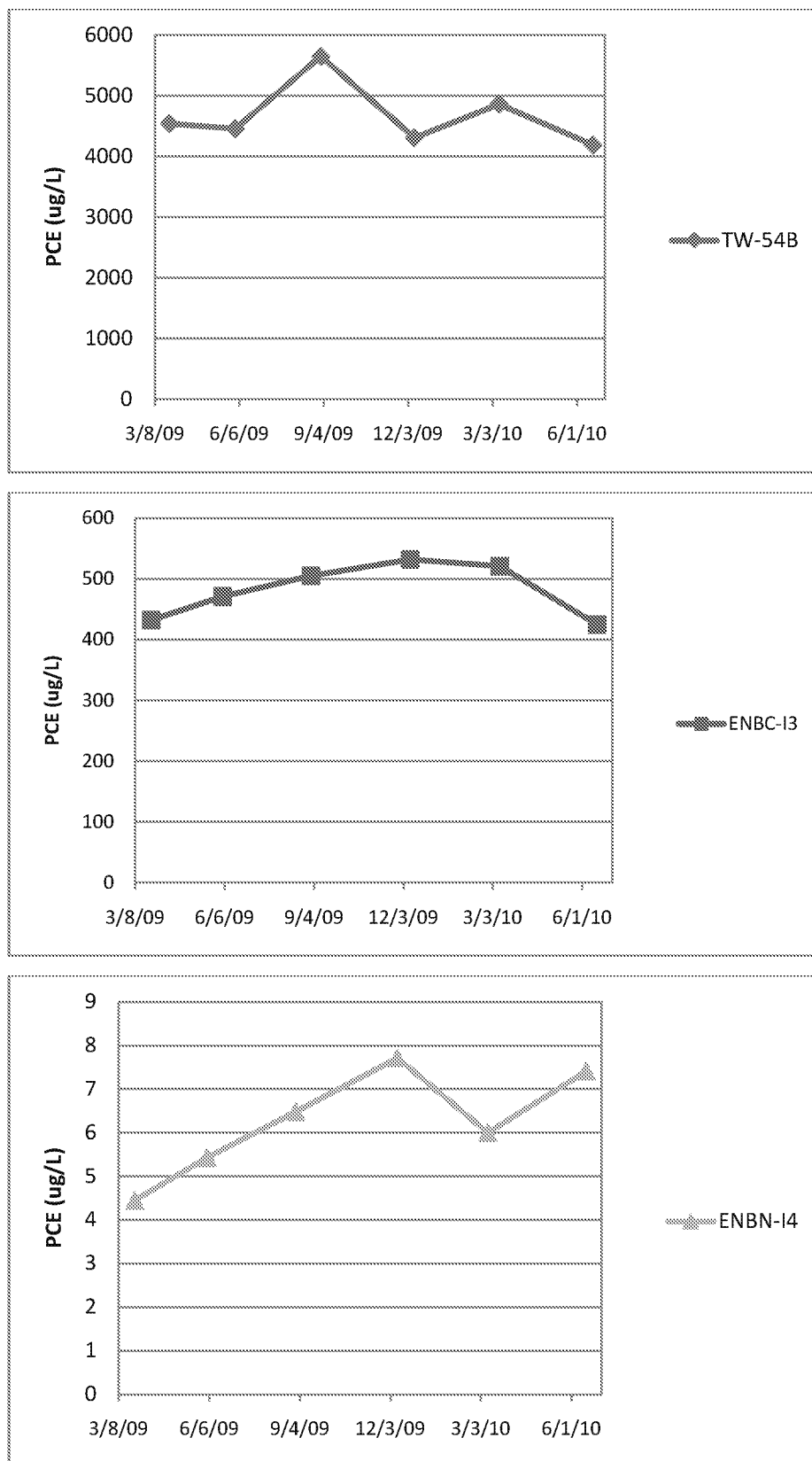
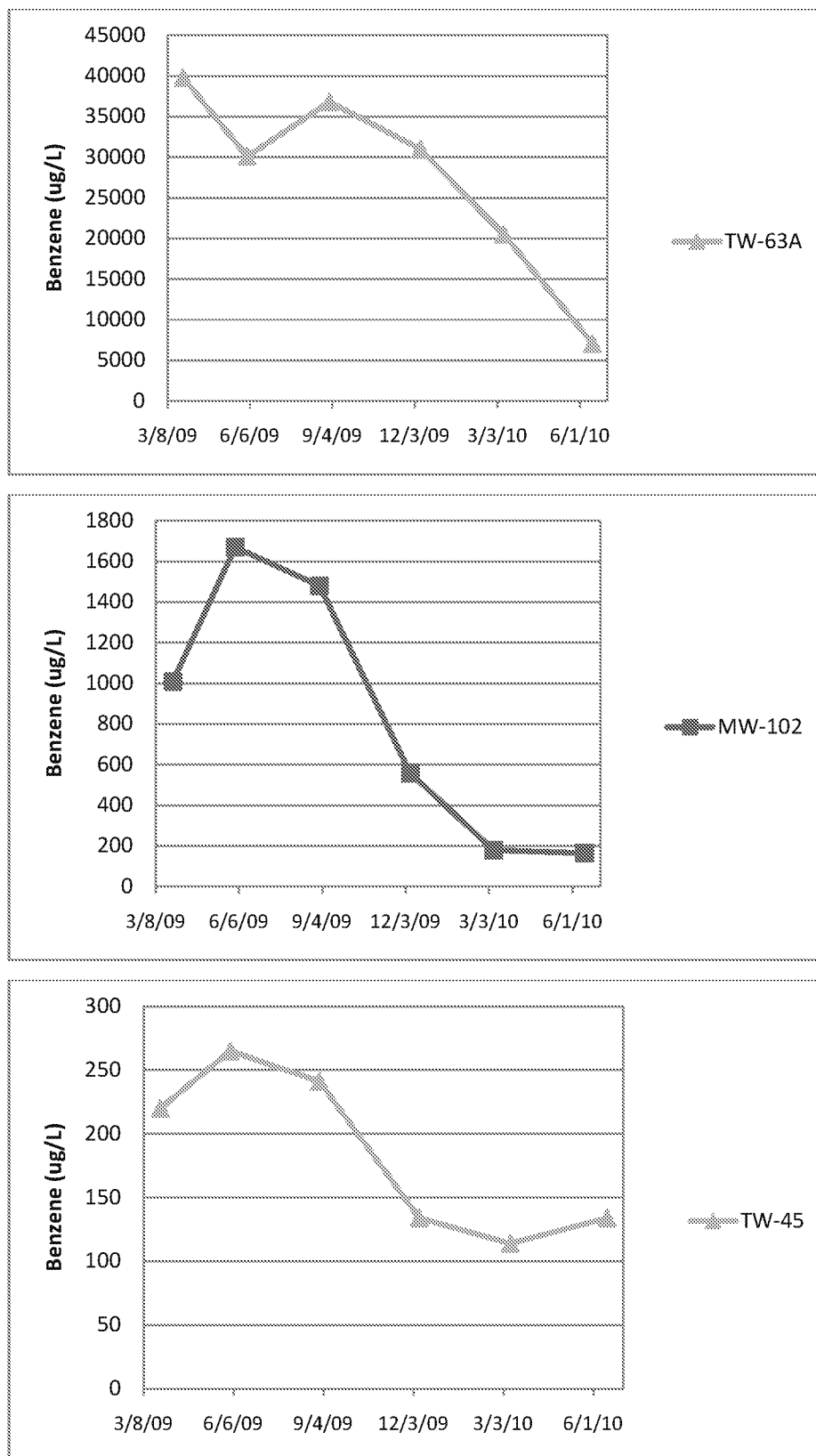


Figure B-6  
Temporal Concentrations of PCE, Deep Aquifer Zone  
Sitewide Groundwater Performance Monitoring Plan  
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**Figure B-7**  
Temporal Concentrations of Benzene, Shallow Aquifer Zone  
*Sitewide Groundwater Performance Monitoring Plan*  
*Institute, West Virginia*



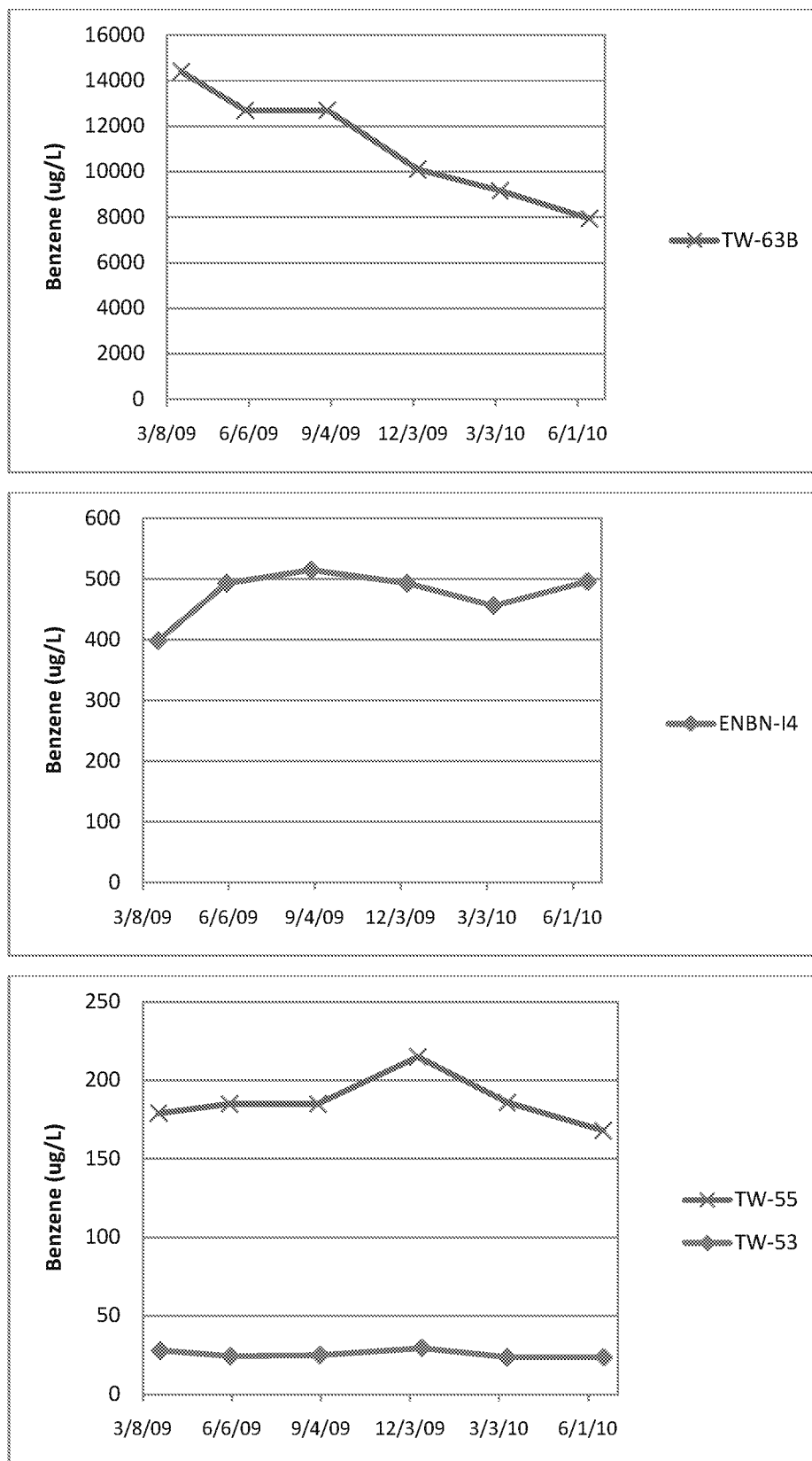


Figure B-8  
Temporal Concentrations of Benzene, Deep Aquifer Zone  
Sitewide Groundwater Performance Monitoring Plan  
Institute, West Virginia



Figures from: *2009 Groundwater Monitoring Report* (CH2M HILL 2010c)





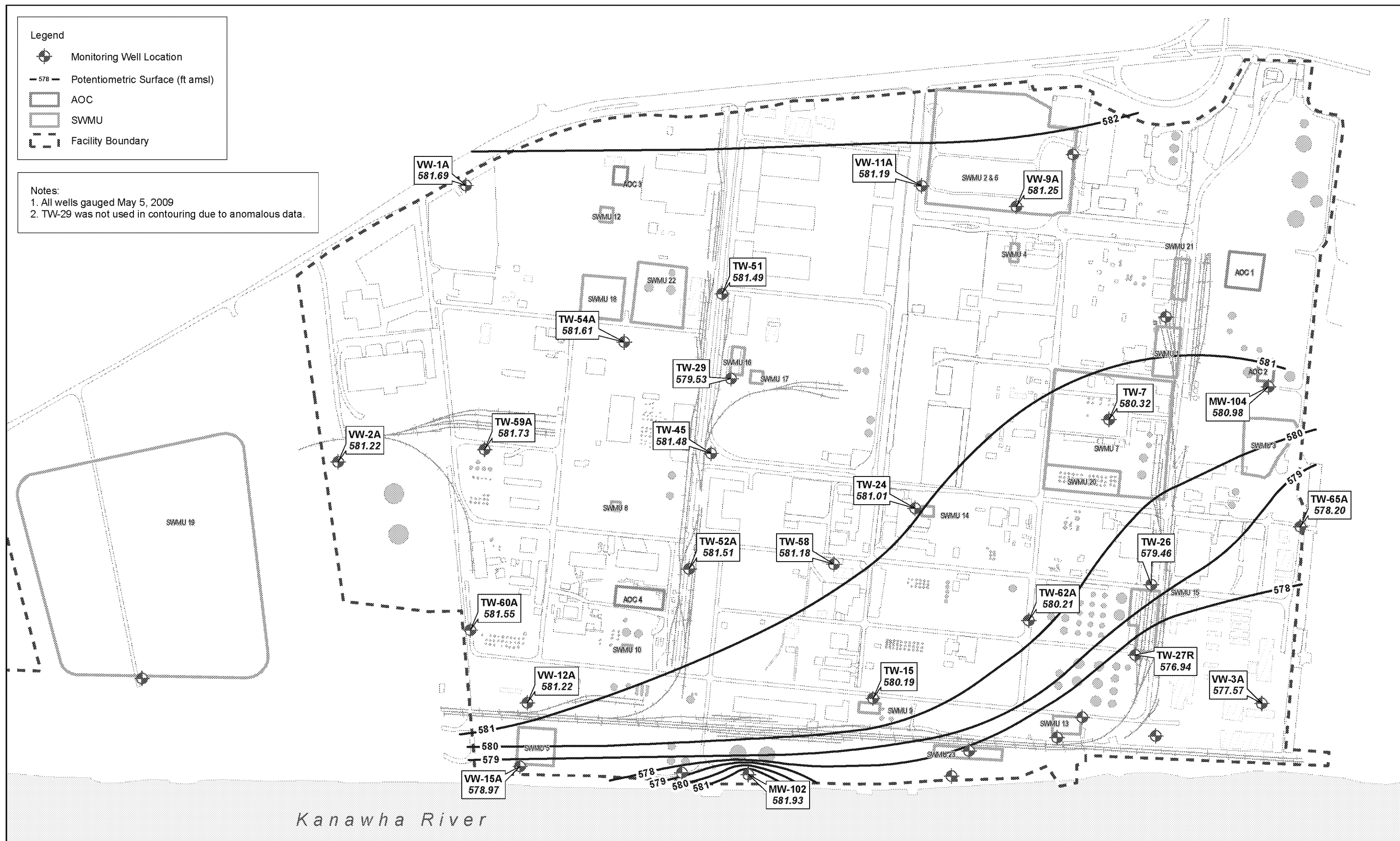


Figure 4-1  
Shallow Aquifer Potentiometric Surface Map - May 2009  
2009 Groundwater Monitoring Report  
Bayer CropScience Institute Facility  
Institute, West Virginia



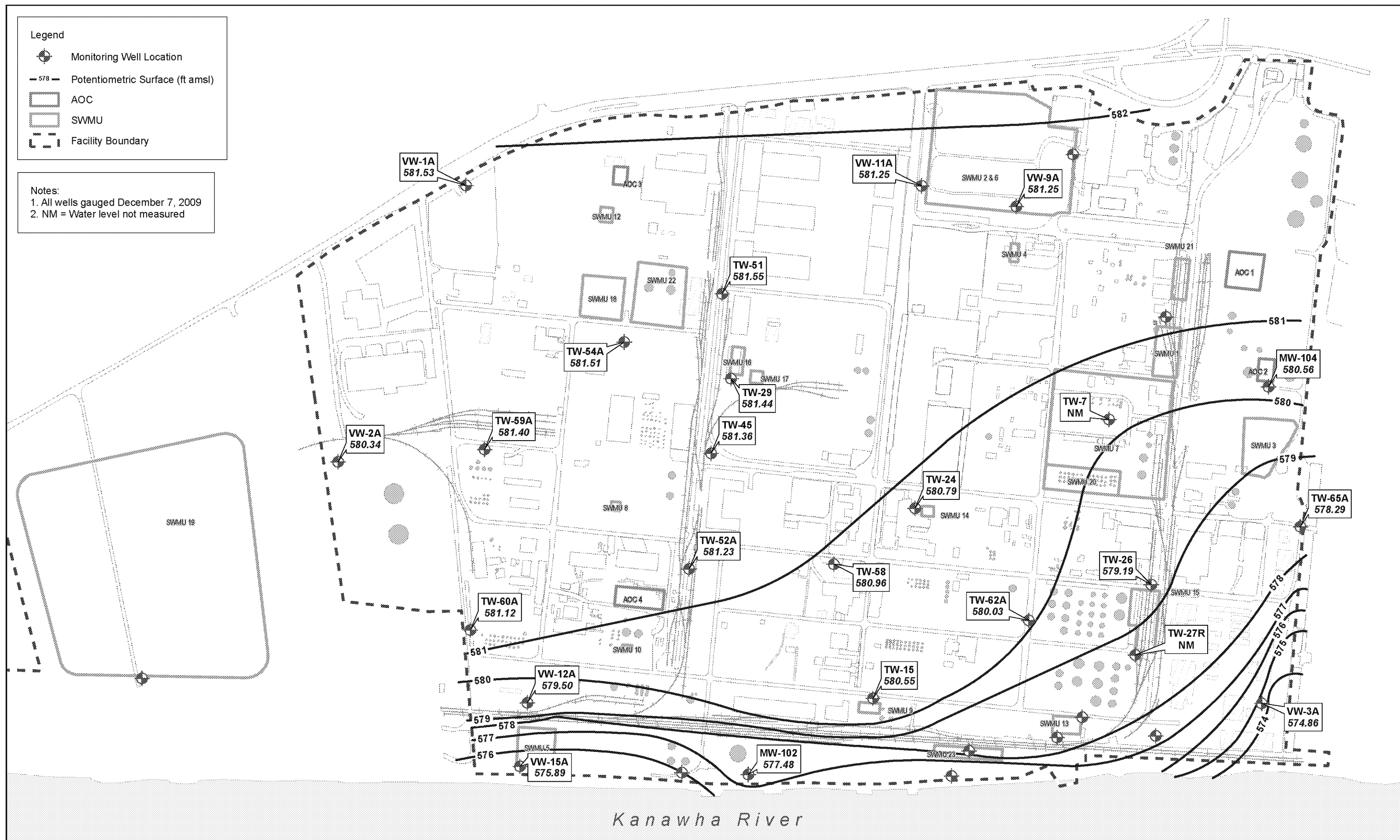


Figure 4-2  
Shallow Aquifer Potentiometric Surface Map - December 2009  
2009 Groundwater Monitoring Report  
Bayer CropScience Institute Facility  
Institute, West Virginia



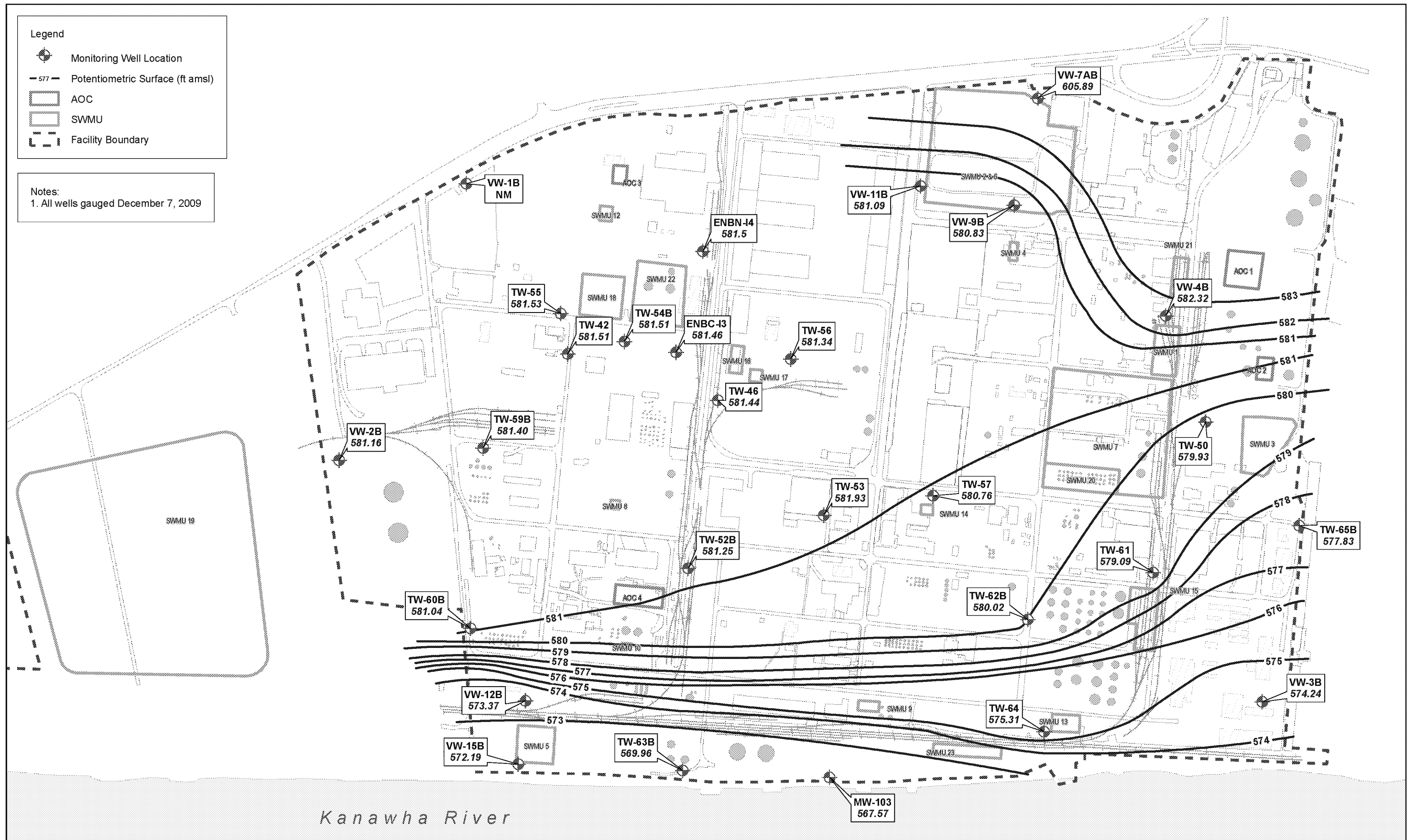
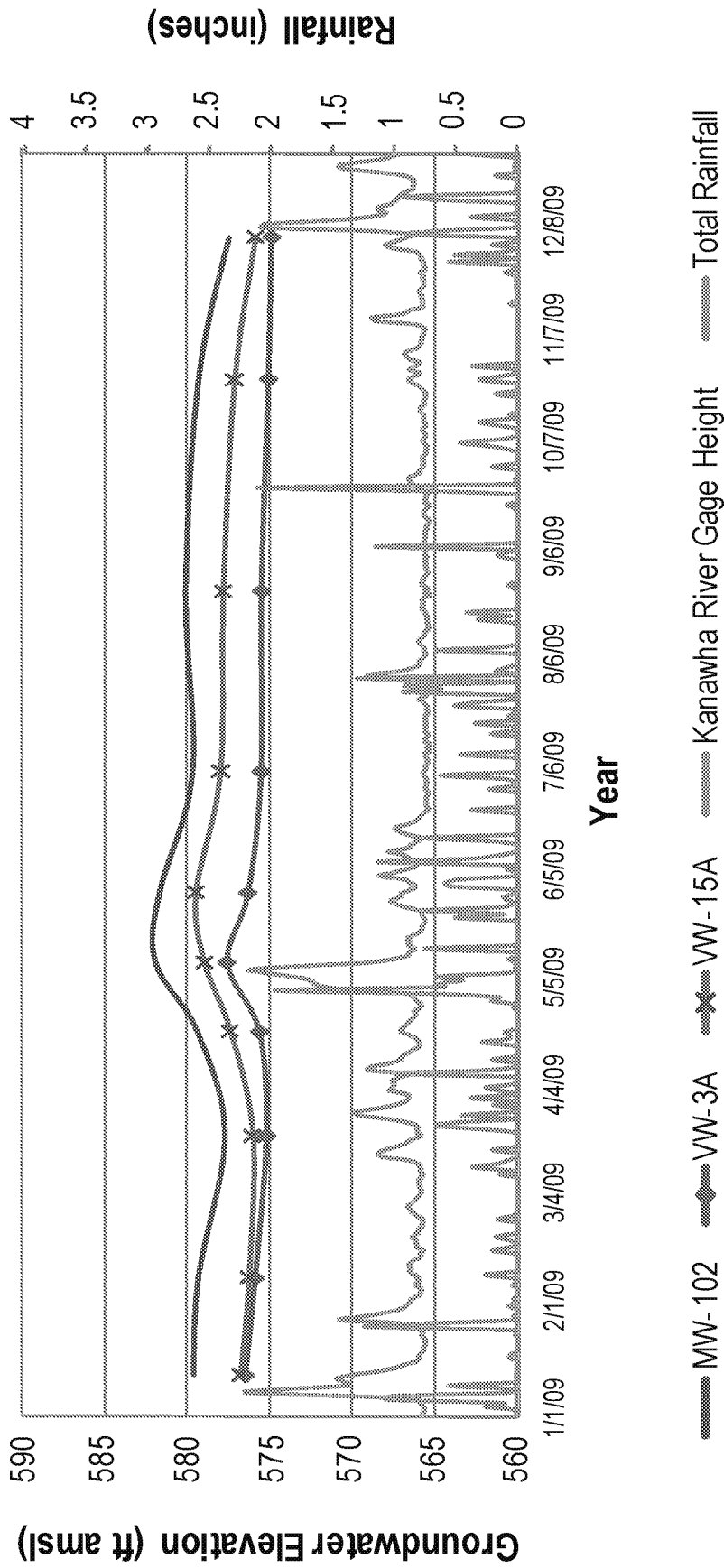


Figure 4-3  
Deep Aquifer Potentiometric Surface Map - December 2009  
2009 Groundwater Monitoring Report  
Bayer CropScience Institute Facility  
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**Figure 4-4**

Shallow Aquifer Groundwater Elevations (Monitoring Wells near Kanawha River)  
 2009 Groundwater Monitoring Report  
 Bayer CropScience Institute Facility  
 Institute, West Virginia





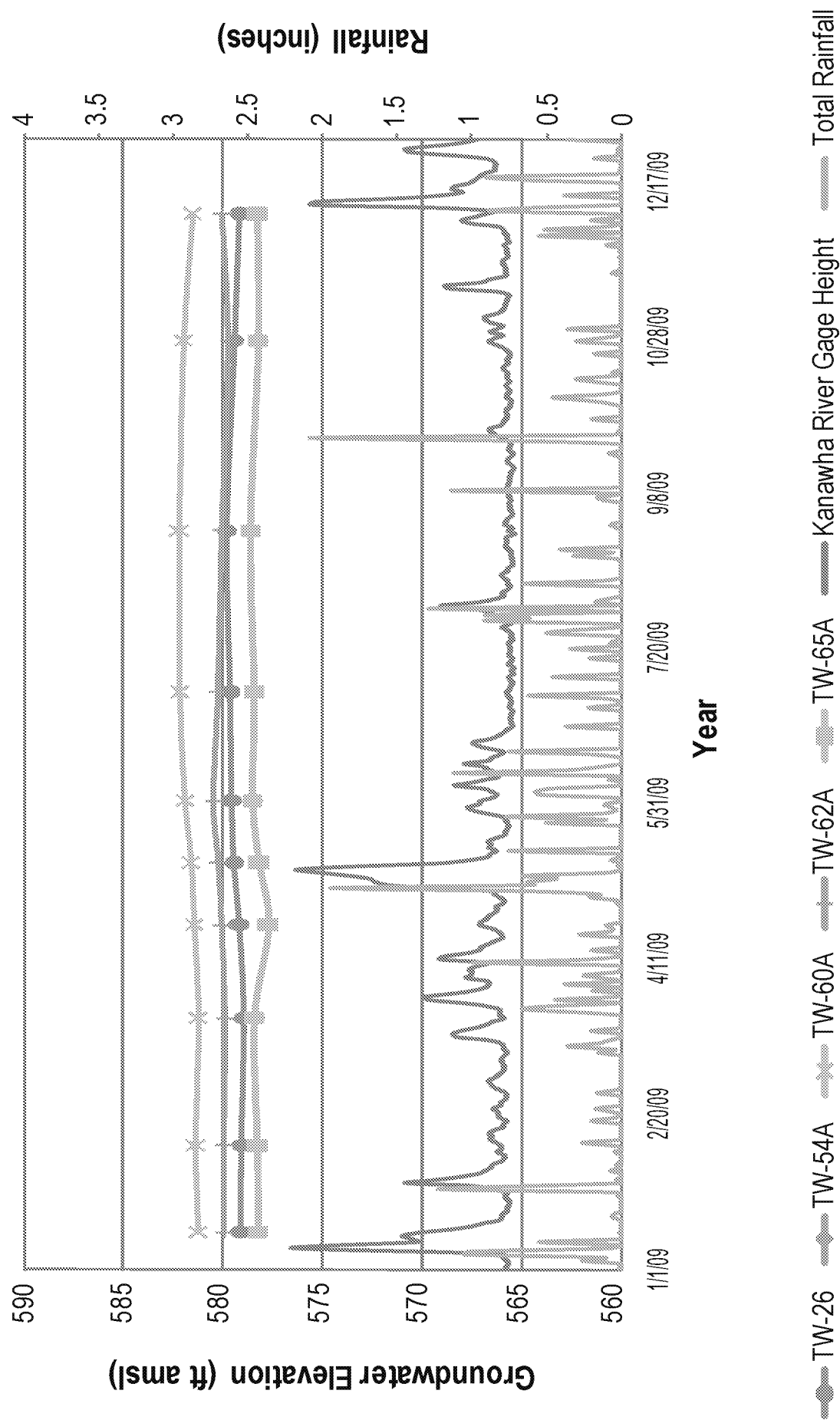


Figure 4-5

Shallow Aquifer Groundwater Elevations (Monitoring Well away from Kanawha River)  
 2009 Groundwater Monitoring Report  
 Bayer CropScience Institute Facility  
 Institute, West Virginia



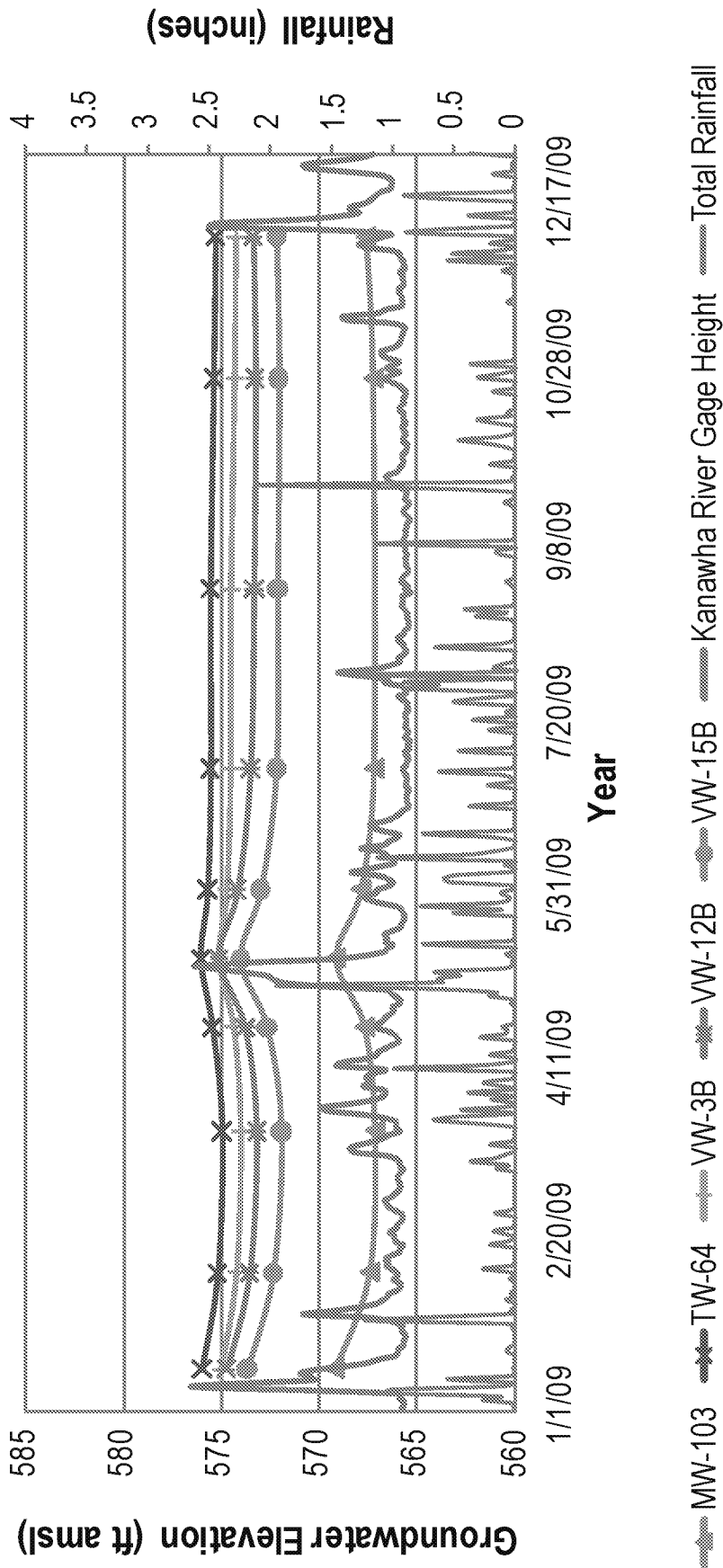
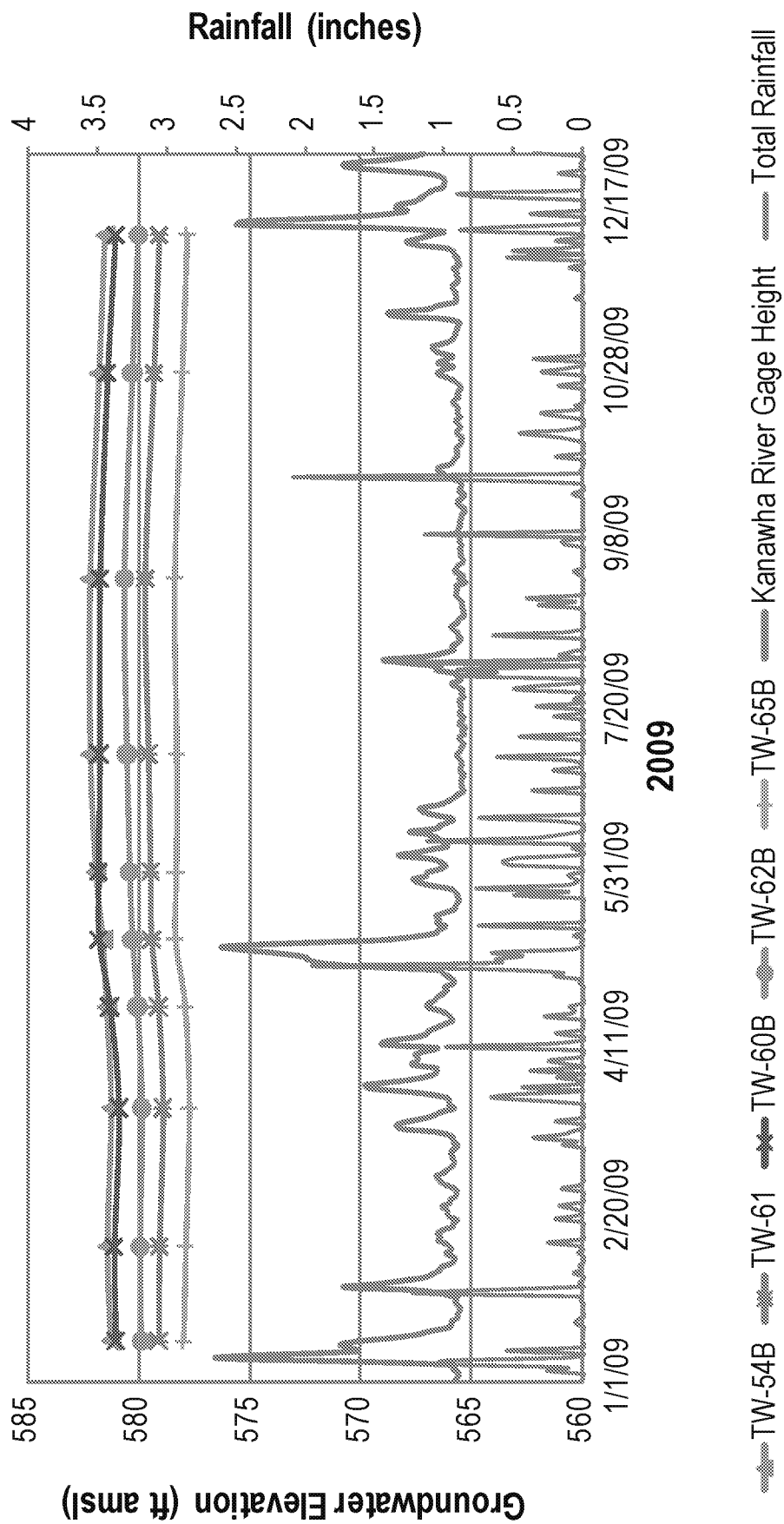


Figure 4-6

Deep Aquifer Groundwater Elevation (near Kanawha River)  
 2009 Groundwater Monitoring Report  
 Bayer CropScience Institute Facility  
 Institute, West Virginia





**Figure 4-7**  
 Deep Aquifer Groundwater Elevation (away from Kanawha River)  
 2009 Groundwater Monitoring Report  
 Bayer CropScience Institute Facility  
 Institute, West Virginia



**Appendix C**  
**Standard Operating Procedures**

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# Water-Level Measurements

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## Purpose and Scope

The purpose of this procedure is to provide a guideline for the measurement of the depth to groundwater in piezometers and monitoring wells, even where a second phase of floating liquid (e.g., gasoline) is encountered. This SOP includes guidelines for discrete measurements of static water levels and does not cover the use of continuously recording loggers.

## Equipment and Materials

- Electronic water-level meter (Solinst® or equivalent) with minimum increments of 0.01 foot; or
- Interface probe (Solinst® Model 122 Interface Meter or equivalent)

## Procedures and Guidelines

### Section 1

Verify that the unit is turned on and functioning properly. Slowly lower the probe on its cable into the piezometer or well until the probe just contacts the water surface; the unit will respond with a tone or light signal. Note the depth from a reference point indicated on the piezometer or well riser. Typically this is the top of the protective casing. If no reference is clearly visible, measure the depth to water from the northern edge of the riser. If access to the top of the riser is difficult, sight across the top of the locking casing adjacent to the measuring point, recording the position of the cable when the probe is at the water surface.

Measure the distance from this point to the closest interval marker on the tape, and record the water level reading in the logbook. Water levels will be measured to the nearest 0.01-foot.

### Section 2

Free product light or dense nonaqueous phase liquid may be present in the piezometer or well. If the presence of free product is suspected, the thickness of the product should be determined using appropriate equipment (e.g., Solinst® Model 122 Interface Meter). The depth to water also is determined with this equipment and the water-level meter should not be used in the piezometer or well as long as product is present. Typically, a constant sound is emitted from the device when free product is encountered and an alternating on/off beep sound is emitted when water is encountered.

The apparent elevation of the water level in the well or piezometer is determined by measuring both the apparent depth to water and the thickness of free product. The corrected water-level elevation is calculated by the following equation:

$$WL_c = WL_a + (\text{Free-product thickness} \times 0.80)$$

Where  $WL_c$  = Corrected water-level elevation

$WL_a$  = Apparent water-level elevation

0.80 = Average value for the density of petroleum hydrocarbon products  
(density value of NAPL should be substituted, if known).

If free product is detected on the surface of the water in the piezometer or well, the value of sampling should be reconsidered because of the potential for contaminating the sampling equipment.

## Attachments

None.

## Key Checks

Before each use, verify that the battery is charged by pressing the test button on the water-level meter. Verify that the unit is operating correctly by testing the probe in distilled or de-ionized water. Leave the unit turned off when not in use.

# Field Measurement of Dissolved Oxygen

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## Purpose

The purpose of this technical practice is to provide a general guideline for field measurement of dissolved oxygen in water samples.

## Scope and Applicability

This technical practice provides information on equipment, materials, and procedures used for standard field dissolved oxygen determination in water samples. Calibration records will be recorded on calibration sheets or in the field logbook. Calibration information to be recorded are the instrument manufacturer, model number, serial number, and calibration media lot number and date of manufacture.

These procedures are to be used unless otherwise specified by the instrument manufacturer.

## Equipment / Materials

- Dissolved oxygen meter
- Dissolved oxygen probe
- Potassium chloride (KCl) probe refill solution
- Spare probe membranes
- Spray bottle with deionized water

## Procedures / Guidelines

### Procedure

1. Before going into the field:
  - Check batteries.
  - Perform calibration.
  - Check probe membrane.
2. Record instrument make, model, and serial number in the log book or data form.
3. Calibrate meter using calibration procedure per manufacturer's recommendation and a duplicate reading every 10 samples.
4. Rinse probe with deionized water.
5. Immerse probe in sample. Record dissolved oxygen reading in the log book or data form, and record the results once the readings have stabilized.

6. Decontaminate the probe and the beaker and then cover to protect them from contamination.

## **General**

- Measurement of dissolved oxygen is temperature dependent. Therefore, temperature correction must be accurate when calibrating.
- Following field measurements:
- Record any problems.
- Compare with previous data and note any large variances.
- Clean all dirt off of the meter and from inside the case.
- Store probe in calibration container with wet towel/sponge.
- Accuracy and precision are dependent on the instrument used. Refer to manufacturer's manual.

## **Key Checks / Items**

- Check batteries.
- Check the membrane.
- Calibrate.
- Decontaminate and cover the probe.

# Field Measurements of pH

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## Purpose

To provide a general guideline for field measurement of pH in water samples.

## Scope

Standard field pH determination techniques for use on surface water and groundwater samples. Calibration records will be recorded on calibration sheets or in the field logbook. Calibration information to be recorded are the instrument manufacturer, model number, serial number, and calibration media lot number and date of manufacture.

These procedures are to be used unless otherwise specified by the instrument manufacturer.

## Equipment / Materials

- pH buffer solution for pH 4, 7, and 10
- Deionized water in squirt bottle
- pH meter
- Combination electrodes
- Beakers
- Solution of HCl
- Glassware that has been washed with soap and water, rinsed twice with hot water, and rinsed twice with deionized water

## Procedures / Guidelines

### Procedure

1. Before going into the field:
  - a. Check batteries.
  - b. Do a quick calibration at pH 7 and 4 to check electrode.
  - c. Obtain fresh standard solutions.
2. Calibrate meter using calibration procedure.
3. Rinse electrode with deionized water between samples.
4. Immerse electrode in sample solution. Record pH reading.
5. Recheck calibration with pH 7 buffer solution after every 5 samples.

Decontaminate pH meter before use at each sample location. Rinse probe with distilled water before storage each day. Check meter for battery charge and physical damage each day. Store meter and pH buffer solution in a cool, dry environment.

## General

1. When calibrating meter, use pH buffers 4 and 7 for samples with pH < 8, and buffers 7 and 10 for samples with pH > 8. If meter will not read pH 4 or 10, something may be wrong with electrode.
2. Measurement of pH is temperature dependent. Therefore, temperatures of buffers and samples should be within about 2°C. For refrigerated or cool samples, use refrigerated buffers to calibrate pH meter.
3. Weak organic and inorganic salts, oil, and grease interfere with pH measurements. If oil or grease are visible, note it on the data sheet. Clean electrode with soap and water, and rinse with a 10 percent solution of HCl. Then recalibrate meter.
4. Following field measurements:
  - a. Report any problems
  - b. Compare with previous data
  - c. Clean all dirt off of the meter and from inside the case
  - d. Store electrode in pH 4 buffer solution
5. Accuracy and precision are dependent on the instrument used. Refer to manufacturer's manual.

## Attachments

- None

## Key Checks / Items

- Check batteries
- Calibrate

## Preventive Maintenance

- Refer to operation manual for recommended maintenance.
- Check batteries. Have a replacement set on hand.

# Field Measurement of Specific Conductivity and Temperature of Water

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## Purpose

To provide a general guideline for the field measurement of conductivity and temperature.

## Scope

Field instruments must be calibrated daily before beginning sampling activities. The methods and frequencies of calibration for the instruments used for each field activity are described. Calibration records will be recorded on calibration sheets or in the field logbook. Calibration information to be recorded are the instrument manufacturer, model number, serial number, and calibration media lot number and date of manufacture.

These procedures are to be used unless otherwise specified by the instrument manufacturer.

## Equipment / Materials

- Reagents - Distilled water in squirt bottle and standard potassium chloride solution
- Reagent Preparation
  - Stock potassium chloride (KCl) solution (1.00 N): Dissolve 74.555 g KCl in distilled water and dilute to 1,000 mL in a volumetric flask.
  - Standard potassium chloride solution (0.01 N): Dilute 10.0 mL of stock 1.00 N KCl solution to 1,000 mL with distilled water using a volumetric pipet and flask.
- Conductivity meter and electrodes
- Beakers or jars, plastic or glass
- Spare size D, alkaline batteries

## Procedures / Guidelines

### Groundwater

Detection limit = 1  $\mu\text{mho}/\text{cm}$  @ 25°C; range = 0.1 to 100,000  $\mu\text{mho}/\text{cm}$   
10  $\mu\text{mhos}/\text{cm}$  = 1 mS/m

## Calibration Check

Check instrument calibration before initial daily use and at least once every 4 hours or every 5 samples, whichever is less. Check instrument with standard solution. Deviations should be noted in the field logbook.

1. Turn on instrument.
2. Hit mode key until “°C” symbol is flashing to indicate temperature corrected results (conductivity units should be  $\mu\text{mhos}$ ).
3. Read standard and note results.
4. Rinse probe with deionized water.
5. Run sample and record results
6. Rinse with deionized water when done.

Decontaminate conductivity meter before use at each sample location. Rinse probe with distilled water before storage each day. Check meter for battery charge and physical damage each day. Store meter and conductivity standard in a cool, dry environment.

## Operation Procedure

1. Perform calibration at beginning and end of the day.
2. Switch mode to Temperature. Allow time for the probe temperature to come to equilibrium with that of the water before reading. Read the temperature on the bottom scale of the meter in degrees Celsius.
3. Switch mode to X100. If the reading is below 50 on the 0 to 500 range (5.0 on the 0 to 50 mS/m range), switch to X10. If the reading is still below 50 (5.0 mS/m), switch to the X1 scale. Read the meter scale and multiply the reading by the mode factor. The answer is expressed in Fohms/cm. Measurements are not temperature compensated.
4. When measuring on the X100 and X10 scales, depress the CELL TEST button. The meter reading should fall less than 2 percent; if greater, the probe is fouled and the measurement is in error. Clean the probe and remeasure.

## Operating Suggestions

- Obstructions near the probe can disturb readings.
- When the calibration test indicates low readings, the probable cause is dirty electrodes. Hard water deposits, oil, and organic matter are the most likely contaminants.
- Caution: Do not touch the electrodes inside the probe. The plating material is soft and can be scraped off.
- If cleaning does not restore the probe performance, replatinizing may be required. Always rinse the probe thoroughly in tap water, then in distilled or DI water after cleaning and before storage. Note that it is best to store conductivity cells in DI water. Collect rinsate water for storage pursuant to the Waste Management Plan.



- Most problems in obtaining good records with monitoring equipment are related to electrode fouling and to inadequate sample circulation.
- Decontaminate conductivity meter before use at each sample location. Rinse probe with distilled water before storage each day. Check meter for battery charge and physical damage each day. Store meter and conductivity standard in a cool, dry environment.
- Water temperature readings can be taken using the conductivity meter. Switch from conductivity mode to temperature mode and record the reading in the field notebook.

## **Attachments**

- None

## **Key Checks / Items**

- Document any deviations from above procedure
- Check battery.
- Check calibration.
- Clean probe with deionized water when done.
- When reading results, note sensitivity settings.

## **Preventive Maintenance**

- Refer to operations manual for recommended maintenance.
- Check batteries. Have a replacement set on hand.

# Low-Flow Groundwater Sampling from Monitoring Wells

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## Purpose and Scope

This procedure presents general guidelines for the collection of groundwater samples from monitoring wells using low-flow purging and sampling procedures. Operations manuals should be consulted for specific calibration and operating procedures.

## Equipment and Materials

- Flow-through cell with inlet/outlet ports for purged groundwater and watertight ports for each probe
- Meters to monitor water quality parameters (e.g., pH, specific conductance, turbidity, dissolved oxygen, oxidation-reduction potential (ORP), and temperature) (e.g., Horiba® U-22 or similar)
- Water-level indicator
- Adjustable-rate, positive-displacement pump, submersible, or peristaltic pump
- Generator
- Disposable polyethylene tubing
- Plastic sheeting
- Well-construction information
- Calibrated bucket or other container and watch with second indicator to determine flow rate
- Sample containers
- Shipping supplies (labels, coolers, and ice)
- Field logbook

## Procedures and Guidelines

### A. Setup and Purging

1. For the well to be sampled, information is obtained on well location, diameter(s), depth, and screened interval(s), and the method for disposal of purged water.

2. Instruments are calibrated according to manufacturer's instructions and information such as make/ model and calibration and use specifications are recorded in the field logbook.
3. The well number, site, date, and condition are recorded in the field logbook.
4. Plastic sheeting is placed on the ground, and the well is unlocked and opened. All decontaminated equipment to be used in sampling will be placed only on the plastic sheeting until after the sampling has been completed. To avoid cross-contamination, do not let any downhole equipment touch the ground.
5. All sampling equipment and any other equipment to be placed in the well is cleaned and decontaminated before sampling in accordance with *SOP Field Sampling Equipment Decontamination*.
6. Water level measurements are collected in accordance with *SOP Water Level Measurements*. **Do not measure the depth to the bottom of the well at this time;** this reduces the possibility that any accumulated sediment in the well will be disturbed. Obtain depth to bottom information from well installation log.
7. Attach and secure the polyethylene tubing to the low-flow pump. Lower the pump slowly into the well such that the pump intake is at least 2 feet above the bottom of the well to avoid mobilization of any sediment present in the bottom. Preferably, the pump intake should be set in the middle of the screen.
8. Insert the measurement probes into the flow-through cell. The purged groundwater is directed through the cell, allowing measurements to be collected before the water contacts the atmosphere.
9. Start purging the well at 0.2 to 0.5 liters per minute. Avoid surging. Purging rates can be increased for more transmissive formations. Record the initial water quality parameters in the field logbook.
10. The water level should be monitored during purging, and, ideally, the purge rate should equal the well recharge rate so that there is little or no drawdown in the well (i.e., less than 0.5 feet). The water level should stabilize for the specific purge rate. There should be at least 1 foot of water over the pump intake so there is no risk of the pump suction being broken, or entrainment of air in the sample. Record adjustments in the purge rate and changes in depth to water in the logbook. Purge rates should, if needed, be decreased to the minimum capabilities of the pump (0.1 to 0.2 liters per minute) to avoid affecting well drawdown.
11. During purging, the water quality parameters are measured frequently (every 3 to 5 minutes) until the parameters have stabilized. Water quality parameters are considered stabilized when measurements meet the following criteria:
  - pH: within 10 percent
  - Specific conductance: within 3 percent

- Dissolved oxygen: within 10 percent
- Turbidity: within 10 percent or as low as practicable given sampling conditions
- ORP: within 10 mV

#### B. Sample Collection

Once purging has been completed, the well is ready to be sampled. The elapsed time between completion of purging and collection of the groundwater sample from the well should be minimized. Typically, the sample is collected immediately after the well has been purged, but this is also dependent on well recovery.

Samples will be placed in bottles that are appropriate to the respective analysis and that have been cleaned to laboratory standards. Each bottle typically will have been previously prepared with the appropriate preservative, if any.

The following information, at a minimum, will be recorded in the logbook:

1. Sample identification (site name, location, and project number; sample name/number and location; sample type and matrix; time and date; sampler's identity)
2. Sample source and source description
3. Field observations and measurements (appearance, volatile screening, field chemistry, sampling method), volume of water purged prior to sampling, number of well volumes purged, and field parameter measurements
4. Sample disposition (preservatives added; laboratory sent to, date and time sent; laboratory sample number, chain-of-custody number, sample bottle lot number)

The steps to be followed for sample collection are as follows:

1. The cap is removed from the sample bottle, and the bottle is tilted slightly.
2. The sample is slowly discharged from the pump so that it runs down the inside of the sample bottle with a minimum of splashing. The pumping rate should be reduced to approximately 100 ml per minute when sampling VOCs.
3. Samples for analysis for volatile organic compounds should be collected first, if such samples are required.
4. Adequate space is left in the bottle to allow for expansion, except for VOC vials, which are filled to overflowing and capped.
5. The bottle is capped, then labeled clearly and carefully.
6. Samples are placed in appropriate containers and, if necessary, packed with ice in coolers as soon as practical.

#### C. Additional remarks

1. If the well goes dry during purging, wait until it recovers sufficiently to remove the required volumes to sample all parameters. It may be necessary to return periodically to the well but a particular sample (e.g., large amber bottles for semivolatile analysis) should be filled at one time rather than over the course of two or more visits to the well.

2. It may not be possible to prevent drawdown in the well if the water-bearing unit has sufficiently low permeability. If the water level was in the screen to start with, do not worry about it because there is no stagnant water in the riser above the screen to begin with.

If the water level in the well is in the riser above the screen at the beginning of purging, then be sure you pump out sufficient volume from the well to remove the volume of water in the riser above the screen. For a 2-inch diameter well, each foot of riser contains 0.163 gallons; for a 4-inch riser, each foot of riser contains 0.653 gallons; for a 6-inch riser, each foot of riser contains 1.47 gallons.

Alternatively, the water in the riser above the screen can be removed by lowering the pump into the well until the pump intake is just below the water level, starting the pump, running it at a low rate, and slowly lowering the pump as the water level in the riser declines. This approach can be terminated when the water level reaches the top of the screen, at which time the stagnant water in the riser has been removed. This may not be a practical approach for dedicated sampling equipment. As with typical low-flow sampling, the flow rate should be kept as low as practicable.

3. There may be circumstances where a positive-displacement or submersible pump cannot be used. An example is at isolated, hard-to-reach locations where the required power supply cannot be brought. In this case, a peristaltic pump may be used. Samples can be collected by the procedures described above for all but those for VOC analysis. The water to be placed in the vials for VOC analysis should not be run through the peristaltic pump but instead should be collected by the following:

- Stop the pump when it is time to collect the VOC sample.
- Disconnect the tubing upstream from the pump (a connector must be installed in the line to do this).
- Holding a finger over the end of the tubing to keep the water in the tubing, remove the tubing from the well. Be sure that the tubing does not contact other than clean surfaces.
- Place the end of the tubing that was in the well into each VOC vial and fill the vial by removing the finger from the other end of the tube.
- Once the vials are filled, return the tubing to the well and collect any other samples required.

4. Non-dedicated sampling equipment is removed from the well, cleaned, and decontaminated in accordance with SOP *Decontamination of Personnel and Equipment*. Disposable polyethylene tubing is disposed of with contaminated PPE.

## Attachments

White paper on reasons and rationale for low-flow sampling.

## Key Checks and Preventative Maintenance

- The drawdown in the well should be minimized as much as possible (preferably no more than 0.5 to 1 foot) so that natural groundwater-flow conditions are maintained as closely as possible.
- Stirring up of sediment in the well should be avoided so that turbidity containing adsorbed chemicals is not suspended in the well and taken in by the pump.
- Overheating of the pump should be avoided to minimize the potential for losing VOCs through volatilization.
- Keep the working space clean with plastic sheeting and good housekeeping.
- Maintain field equipment in accordance with the manufacturer's recommendations. This will include, but is not limited to:
  - Inspect sampling pump regularly and replace as warranted
  - Inspect quick-connects regularly and replace as warranted
  - Verify battery charge, calibration, and proper working order of field measurement equipment prior to initial mobilization and daily during field efforts

## **Attachment to the SOP on Low-Flow Sampling Groundwater Sampling from Monitoring Wells White Paper on Low-Flow Sampling**

EPA recommends low-flow sampling as a means of collecting groundwater samples in a way that minimizes the disturbance to the natural groundwater flow system and minimizes the introduction of contamination into the samples from extraneous sources. The following are details about these issues.

When a pump removes groundwater from the well at the same rate that groundwater enters the well through the screen, the natural groundwater-flow system around the well experiences a minimum of disturbance. Some disturbance is bound to occur because you are causing groundwater to flow to the well in a radial fashion that otherwise would have flowed past it. However, the resulting low-flow sample provides the most-representative indication we can get of groundwater quality in the immediate vicinity of the well.

Normally, when a well is pumped at an excessive rate that drops the water level in the well below the water level in the aquifer, the water cascades down the inside of the well screen when it enters the well. The turbulence from this cascading causes gases such as oxygen and carbon dioxide to mix with the water in concentrations that are not representative of the native groundwater and are higher than expected. This causes geochemical changes in the nature of the water that can change the concentrations of some analytes, particularly metals, in the groundwater sample, not mention it's effect on the dissolved oxygen levels that then will be measured in the flow-through cell. Such turbulence also may cause lower-than-expected concentrations of volatile organic compounds due to volatilization.

For wells in which the water level is above the top of the screen, the water up in the riser is out of the natural circulation of the groundwater and, therefore, can become stagnant. This stagnant water is no longer representative of natural groundwater quality because its pH, dissolved-oxygen content, and other geochemical characteristics change as it contacts the air in the riser. If we minimize the drawdown in the well when we pump, then we minimize the amount of this stagnant water that is brought down into the well screen and potentially into the pump. As a result, a more-representative sample is obtained.

Typically, wells contain some sediment in the bottom of the well, either as a residue from development that has settled out of the water column or that has sifted through the sand pack and screen since the well was installed. This sediment commonly has adsorbed on it such analytes as metals, SVOCs, and dioxins that normally would not be dissolved in the groundwater. If these sediments are picked up in the groundwater when the well is disturbed by excessive pumping, they can:

- Add unreasonably to the measured concentration of SVOCs and other organic compounds

The SOP for low-flow sampling has been modified recently and should be consulted for additional information about low-flow sampling and ways of dealing with wells in which the water level cannot be maintained at a constant level.